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THE BRITISH JOURNAL OF METALS

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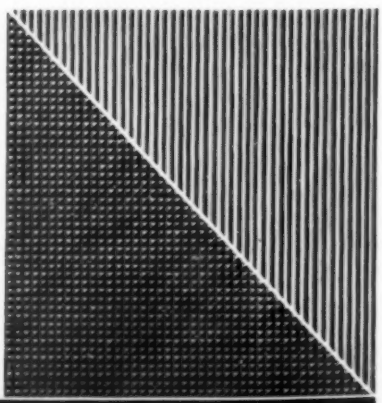

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METALLURGIA

The British Journal of Metals

(INCORPORATING THE METALLURGICAL ENGINEER.)

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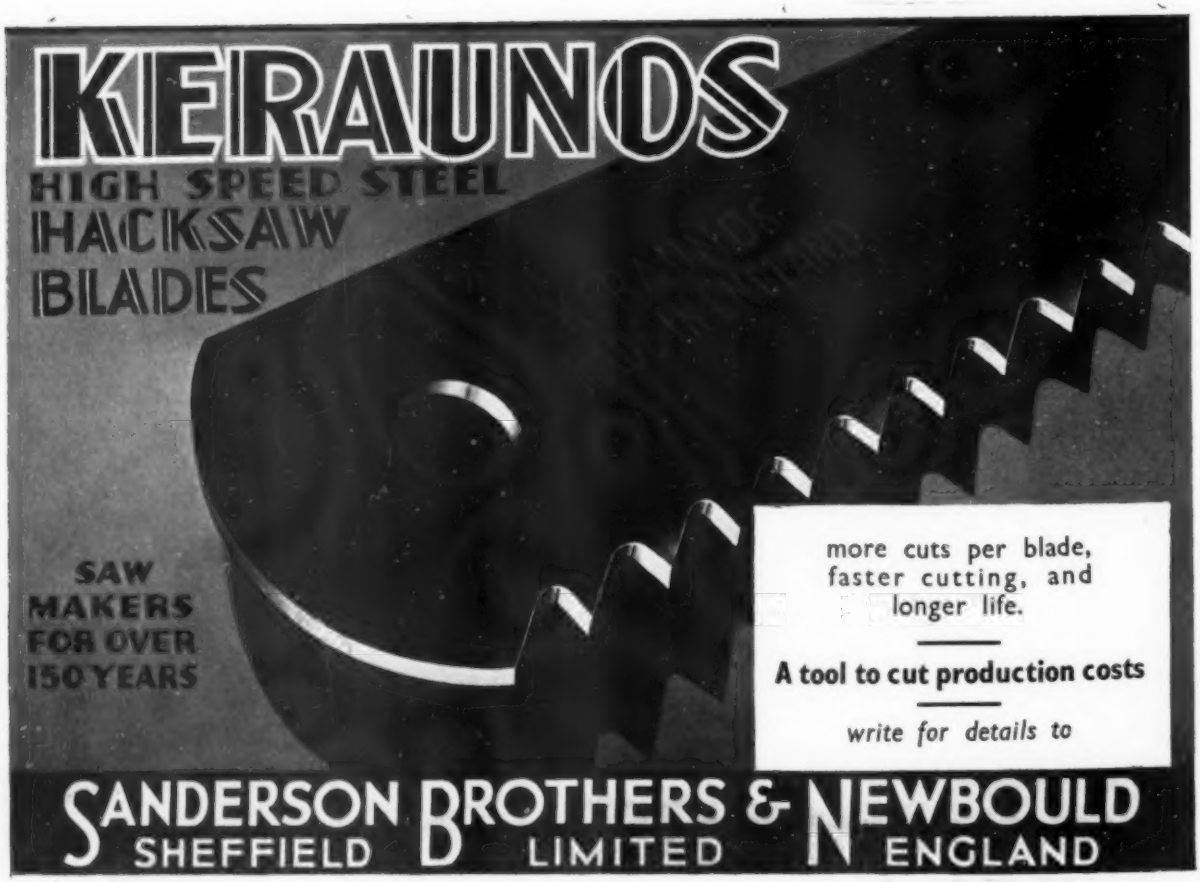
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NOVEMBER, 1939. VOL. XXI, No. 121.

Temperature Control and its Importance in the Metallurgical Industries

An important factor in the production of uniformly-heated products is temperature control, and in this article are discussed improved methods of control which have been developed to facilitate closer control of production. The main types of regulators most frequently used for large furnaces are considered.

THE shortage of skilled labour, in recent months, together with the demands of modern specifications calling for closer control of production, have presented both metallurgists and fuel engineers with increasingly difficult problems. The wider application of instruments to industry, and particularly the development of improved methods of control have helped largely to relieve the position.

Of major importance in the metallurgical industries is the accurate and economic control of electric, gas, and oil-fired furnaces, and it is therefore proposed to discuss some of the instruments that have been developed for such applications, and to give a general survey of the various types of regulators available, together with a description of their individual characteristics.

Before commencing this survey, it may be desirable to correct certain misapprehensions which sometimes arise as to the probability of securing "straight-line" control; this condition infers that the temperature once attained will not vary by an amount readable on the indicator scale or recording chart of the controller. It will be obvious from a brief consideration that such a condition cannot be acquired solely by the automatic regulator, as it must be largely influenced by the design of the furnace and both the sensitivity of the heat-receiving unit and any lack of uniformity in the conditions within the furnace; for instance, if a furnace is badly lagged and loses heat quickly, or if the convection currents within are great, then, no matter how sensitive the regulating mechanism may be, the controlled temperature is bound to oscillate between certain limits depending upon the efficiency of the furnace.

Straight-line records from a controller can be easily acquired by making the recorder insensitive, by placing the heat-receiving unit in such a position in the furnace that it is not affected by rapid fluctuation in temperature, or by lagging the heat-receiving unit so that the quick changes of temperature are not detected, but such records are obviously not a true indication of the real temperature conditions.

It will be appreciated from the foregoing remarks that a "saw-tooth" record may be a more reliable indication of accurate and effective control than a straight line. In any case, it cannot justly be claimed that any regulator will give straight-line control without reference to the conditions under which the instrument is to work. Indeed, it is correct to say that if the regulator is sufficiently sensitive and the heat-receiving units are properly placed, then "hunting" or temperature variations within limits are bound to occur and be shown on the scale or chart. It is partly to show these variations and keep them within permissible bounds that recording regulators are installed.

Modern furnace installations are mostly of such excellent design that regulation can be maintained within very narrow limits, but when older types of existing furnaces, previously hand-controlled, are to be converted to automatic control, then expert advice should be sought if reasonably accurate results are to be obtained; in any case, close co-operation between supplier and user of the apparatus is essential for satisfactory operation.

Fig. 1.—Recording Potentiometer.

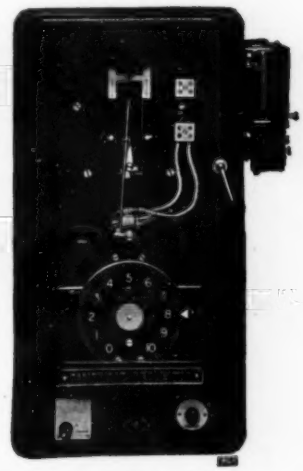

Fig. 2. Potentiometric Regulator.

In order to summarise the types of regulator now most frequently used for large furnaces, and to describe the principles by which they operate, it is necessary to divide them into two main groups—i.e., those which operate on potentiometric principles, and those which operate by the direct-deflection of a galvanometer in conjunction with a "chopper" mechanism.

Potentiometric Controllers

The potentiometric controllers, examples of which are shown in Figs. 1, 2, 3 and 4, are suitable for use in conjunction with either base or rare metal thermo-couples, resistance thermometers, Fery telescopes, or other suitable electrical means whereby the temperature or other condition to be controlled is measured. Normally, they work upon the potentiometric principle, but when used with electrical resistance thermometers they operate as Wheatstone bridges.

Instruments are made to control temperatures from −200° C. to 2,000° C., and when using thermo-couples, many manufacturers fit an automatic cold junction compensator in the instrument. A "broken thermo-couple" device which switches off the furnace if the thermo-couple circuit is broken, can often be incorporated, thus preventing wholesale spoilage.

With this type of instrument it is possible to use any length of connecting lead without affecting the accuracy of calibration; the controller may thus be situated at a position remote from the furnaces. The current for the potentiometer circuit is usually supplied by a dry cell

which normally lasts for about a year, and need only be standardised once in 24 hours; this is a simple operation, but if desired, many makers are prepared to fit automatic standardisation devices. These controllers can be obtained for any voltage, and when it is found necessary to mount the instruments in positions where light is limited, many manufacturers will provide a system of internal illumination.

Fig. 1 shows a recording potentiometric controller of the slide-wire type, but, instead of the contact being adjusted by hand until balance is obtained, this is done automatically by the recorder mechanism. The charts may be driven at speeds varying from half an inch per hour to two inches per hour, and are usually of sufficient length to last for one month. The used portion of these charts may either be automatically wound on a second roller, allowing a considerable portion of the chart to remain visible, or are arranged to project through the bottom of the case where it can be easily torn off. With potentiometric controllers it is possible to "set up" the scale so that the whole width of the chart corresponds to the working range, the minimum range being dependent upon the type of sensitive element used. This feature is, of course, of great importance where processes are required to be controlled with an extremely high order of accuracy.

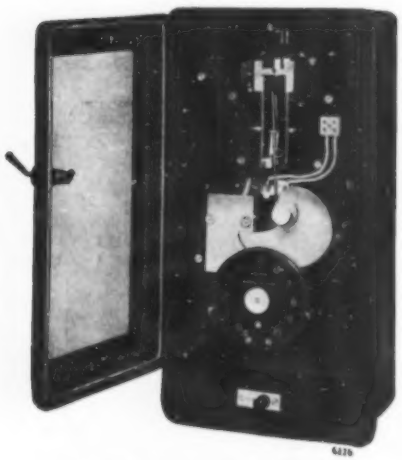

Fig. 3.—Potentiometric Time-Temperature Regulator.

The self-contained mercury switches usually provided in this type of regulator are rated at about 10 or 20 amperes; for higher currents external contactors are employed. Contactors can also be provided to operate alarm signals, coloured lights or other devices. Automatic standardisation is now frequently specified on this type of recorder, making the controller completely independent of personal supervision over considerable periods. The standardisation device operates regularly by means of a cam switch, and a warning signal visible in a small window beneath the chart indicates when a new cell is required. Such recorders can be obtained to give up to six records on one chart.

In the instrument illustrated the motor driving the recorder mechanism also winds the chart clock through a safety device, so that it is kept fully wound without risk of over-winding; thus in the event of a power failure stopping the motor, the chart will continue to run for several hours, recording the period during which the failure occurred. The chart may be stopped by operating a small lever inside the case. Recording regulators operated by A.C. synchronous motors also are available for applications where exact uniformity of the time scale is of essential.

Controllers of the type illustrated in Fig. 2 operate on a principle similar to that of the recording instrument described above, and are used where it is desired accurately to control the temperature without obtaining direct indication or records on the controlling instrument. The actual temperature at any time can be determined when required by rotating the calibrated dial until the galvanometer rests at zero, when the value will be indicated. The scale of this instrument can be "set up" to any desired figure, the minimum range being dependent upon the type of sensitive element used. In this manner the working range can be spread over a long control scale, thus giving open, clearly-marked calibration, with greatly-increased accuracy. The manufacturers claim that the accuracy of instrument operation obtainable with this type of instrument is $\pm 0{\cdot}1\%$ of full scale (i.e., 1° for a range of 1,000°). Normally, the self-contained mercury control switches are rated at about 10 amperes, but regulators with switches suitable for breaking circuits up to 30 amps. are available for special applications.

The potentiometer regulator illustrated in Fig. 3, is fitted with a time-temperature mechanism arranged to vary the setting of the controller in accordance with a desired time-temperature curve. On this instrument control is adjusted by means of a cam which can be rotated at a speed of one revolution in any given period. The cam could be shaped, for example, to increase the temperature of a furnace at any desired rate to an adjustable maximum, and then, if necessary, could be arranged to hold the temperature constant for a pre-arranged period. Blanks of thin brass are supplied with these instruments which may be cut by the engineer according to the control curve he desires to obtain. The maximum temperature to be reached can often be set independently of the cam, by adjusting a movable stop on the temperature dial, whilst these instruments can be used as ordinary regulators by simply removing the cam and setting the control stops to the desired temperature. The use of such a controller ensures uniformity in the different batches undergoing treatment.

There is now on the market a controller similar to the one described above, but without the time-temperature cam, which can be used to control a number of furnaces or zones of one furnace at different temperatures. This instrument, illustrated in Fig. 4, incorporates a zone distributor arranged automatically to switch into circuit each zone in turn; the distributor is operated by the driving motor of the controller, and the speed of operation is such that the connections are changed over once every few seconds, a complete cycle of control thus being rapidly obtained.

Direct Deflectional Controllers

The instrument illustrated in Fig. 5 is an example of the direct deflectional type of controller. These instruments combine the function of a temperature regulator and an indicator, the actual temperature being shown on a clearly-marked scale about 10 in. long. The point of control can be adjusted by means of a key which sets a separate pointer to the desired temperature on the scale. In this type of instrument the temperature, determined by the sensitive element, is indicated on the horizontal scale by the pointer of a moving-coil galvanometer of the high-resistance millivoltmeter type. This pointer is provided at its extremity with a small knife edge, and is arranged to swing freely below a "chopper" bar, which is automatically depressed at regular intervals. When the control point is reached by the galvanometer, the chopper bar operates mechanism which actuates a mercury switch, thus switching off the source of heat. When the temperature commences to fall, the mechanism again automatically operates the switch, in the reverse direction, thus maintaining correct temperature. When these instruments are used with thermo-couples, the manufacturers provide cold junction temperature compensating devices which automatically compensate for ambient temperature variations. Also "broken thermo-couple" safety devices are usually fitted. This device operates as follows:—

The thermo-couple employed as the sensitive element is arranged to form one arm of a Wheatstone bridge to which is connected a dry battery; the galvanometer being that employed in the regulator system. Normally the thermo-couple resistance is balanced by a fixed coil, so that no E.M.F. from this bridge device will flow in the galvanometer circuit. Should a break occur in the thermo-couple circuit the bridge would immediately be thrown out of balance and the regulator galvanometer deflected

to the zero position. The effect of this is to close down the furnace until a new thermo-couple is inserted. A check is provided by enabling the thermo-couple to be readily open circuited, and the consequent behaviour of the regulating mechanism noted. This type of instrument can be provided with a zone distributor. Such a device fitted to one regulator allows a number of zones or separate furnaces to be controlled at the same temperature by a single instrument.

As well as the normal switching devices employed in the instruments described above, these controllers can also be fitted with an additional switch, arranged to cut out some of the furnace-heating elements when the temperature reaches a few degrees below the control point, thus preventing the possibility of "overshoot" occurring with rapid heating, and eliminating "hunting."

The direct-deflectional instrument can also be employed as an automatic alarm indicator in installations where it is desired to obtain immediate warning of excessive temperature. For this purpose the instrument is provided with a system of contacts which can be arranged to operate coloured lights, Klaxon alarm signals, or other devices. Lamps may be arranged, for instance, to show green and white when the temperature is too low, white only when correct, and red and white when too high. These instruments can also be obtained with multi-point switches (see Fig. 6) operated by a driving motor, and enabling any number of sensitive elements up to 25 to be connected in rotation, the usual period of connection for each being about 15 secs. If the predetermined temperature is exceeded, a mercury switch operates an alarm, whilst the motor is automatically stopped; the position of the multi-point switch then indicates the sensitive element causing the alarm. If desired, the switch can be rotated by hand at any time, for checking individual elements.

Before concluding the summary of the various forms of electrical regulators, an interesting instance of the increasing numbers that are being employed is the recent installation of 40 time-temperature controllers similar to the type illustrated in Fig. 3, with separate potentiometric recorders similar to Fig. 1. These regulators are used to control the temperature of Birlec furnaces used for heat-treatment, the instruments being centralised in a specially-provided control room, and forming what is believed to be the largest installation of automatic regulators ever employed in this country.

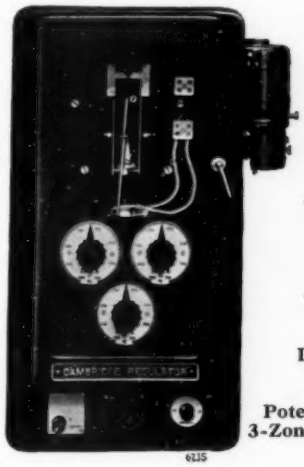

Fig. 4.
Potentiometric 3-Zone Regulator.

Fig. 5.
Direct-Deflectional Regulator.

Fig. 6.
Alarm Indicator.

In mounting an automatic temperature-control outfit it is frequently desirable to instal the instruments on one panel, giving greater accessibility together with considerable economy of floor space. The internal wiring of the instruments is then made to a convenient terminal board, thus greatly facilitating the connection of external circuits.

We are indebted to the Cambridge Instrument Co. Ltd., for the loan of electros used to illustrate this article and take this opportunity of expressing our thanks for their courtesy and helpfulness.

A Magnetic Balance of Saturation Measurement

The Saturation Points of Cementite and Carbon Steels Dependent on Temperature and Preliminary Treatment

THE methods of saturation measurement by means of magnetic balances, as described in literature, show some deficiencies; especially is the accuracy of measurement insufficient. Heinrich Lange and Karl Mathieu, therefore, developed a new instrument, incorporating the following considerations: the intensity of the magnetic field should be great enough to guarantee measurement of the test-pieces whilst in a state of saturation; the temperature of the test-pieces should be adjustable between 20° and 1,200° C. during the measurement; the instrument should be so sensitive that it can record measurements of the same test-piece in both the ferro-magnetic and para-magnetic states; and the degree of magnetism must be registered very quickly, fast enough to make possible observation of rapid transformations.

The authors describe the design of the instrument, and the manner in which it was calibrated. They show that the magnetic saturation points of various materials can be determined, as well as their dependence on the temperature. Also, the course of the transformation processes can be observed. Thus, the effect of the carbon content, of the temperature, and of the preliminary heat-treatment on magnetic saturation point of carbon steels could be demonstrated, and conclusions could be drawn as to the magnetic saturation point of iron carbide. It is also possible to investigate chemical reactions with this balance; for example, the carburisation of iron by means of benzol vapour has been studied, thereby determining accurately the specific saturation of cementite.

Mitteilungen des Kaiser-Wilhelm-Institut für Eisenforschung in Düsseldorf. Vol. XX. No. 18.

The Hardness Testing of Chilled Cast Rolls

VARIOUS difficulties arising from time to time in ascertaining the hardness of chilled rolls have engaged the attention of the White and Chilled Iron Sub-Committee of the British Cast Iron Research Association. As a result the Sub-Committee has prepared a report giving the recommended method of taking these tests. This report, issued as Special Publication No. 3, is available from the British Cast Iron Research Association, 21-23, St. Paul's Square, Birmingham, at the price of 6d. post free.

The Sub-Committee consider that instruments used on chilled or white cast iron should be regularly calibrated on chilled or white cast iron standards, rather than on steel standards usually supplied. Suitable chilled blocks are being prepared for test on a variety of scleroscope instruments to see whether the use of chilled iron standards should be recommended.

Electric Tropenas Alloy Steel Manufacture

Using, primarily – air for complete reduction, and, secondary – electric arc heating, after the additions of alloys. (Campbell System.)

A new steel process is described which is claimed to be both rapid and economical. As the title implies complete reduction is carried out on the Tropenas principle, and after the addition of alloys the metal is further heated by electric arc, the whole process being carried out in a single unit. The plant is suitable for the production of quantities ranging from half a ton to three tons per hour, and may be applied to the production of carbon and alloy steels and also special high-duty cast irons.

INTRODUCING new or modifying old processes, and/or introducing new or improving old products; overcoming difficulties and eliminating defects; and seeking means to facilitate production with reduced working costs are among the most important problems constantly engaging the attention of those engaged in the iron and steel industry. These problems present a very wide field, but the collaboration and co-operation of the scientist, the electro and chemical metallurgists, and manufacturers and their personnels, have resulted in the production of steels of improved mechanical and more useful physical properties, corrosion- and acid-resisting irons and steels. The technique necessary to give increased reliability has progressed with the development of new steels, and this also applies to improved methods of production, but one of the problems mentioned, that of further increasing production with reduced costs, offers considerable scope for continued research. It is in connection with this latter problem that a method of steel manufacture has been developed which is not only claimed to increase production, but also ensures lower working costs, both as regards the use of fuel or energy in the metallurgical and reheating processes, and in the saving of labour costs.

As the name implies, the basis process is carried out on the Tropenas principle, and the plant comprises a Tropenas furnace with especially designed electrical equipment for raising the bath temperature after additions of the alloys. Both the normal processes appertaining to the well-known Tropenas and electrical heating are incorporated in the one furnace. Adding large quantities of alloys, such as nickel, chromium, etc., to blown Tropenas charges presents many difficulties. The initial temperature is unduly lowered and complete solubility of the alloys is uncertain. The addition of alloys preheated to a semi-plastic condiiton is also unsatisfactory.

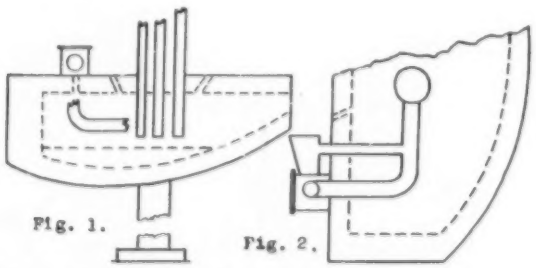

Fig. 1.

Fig. 2.

With the object of utilising the practical advantages of the Tropenas furnace for speedy production, the addition of special electrical equipment facilitates heating the charge after alloy inclusions have been made, and makes possible the production of stainless alloy steel and special high-duty cast irons to practically any specification. By this process the superheating of ordinary commercial carbon steels for running small castings of intricate and thin design may be accomplished in approximately 15 mins. For low alloy steels, the superheating and consequent solubility of the alloy additions is accomplished in about the same time, though for high alloy additions this time will be exceeded.

The furnace, by which this process is performed, is of unique design, as is shown in Fig. 1; it is completely rectangular in section, instead of the usual circular shape. Attached to the tuyere box, Fig. 2, is a sealed hopper containing one or more partitions. Granulated ferro-silicon, manganese, nickel or chromium may be fed into the bath during blowing operations, by means of tubes leading into the tuyere orifices, which are impelled forward into the molten iron. Attached to the main air pipe and connected with the hopper is an air-balancing conduit. This arrangement for adding, say, high-grade silicon for supplying extra heat units, is extremely effective, and more economical than throwing lump silicon materials into the mouth of the converter during the blowing period.

The attachments, when not required, in no way obstruct the normal working of the process. The electrical operation of superheating may be brought into operation after the slag has been removed or otherwise, but preferably the slag should be removed. A section of the furnace—the tuyere side—carrying part of the refractories is removed. A replica section containing the electrodes is lowered into position and the arcs adjusted, the operation occupying a few minutes only. A light removable refractory cover seals the converter mouth. On completion of the heating, the electrical portion is removed, the solid section is replaced and the charge poured.

The process offers many advantages for the production of special high-duty cast-iron alloys. Cupola iron may be reduced quickly in carbon and silicon, additions made for inoculation and superheating, or alloys may be added. Other combinations and uses will be obvious to practical foundrymen and metallurgists. Further, a basis iron containing under 0·1% carbon or silicon may be readily obtained under half an hour. The addition of an equal amount of cupola iron and a short period of electrical superheating produces an iron of exceptional physical qualities, which can be consistently reproduced.

The average time taken to produce one ton stainless steel alloy is shown in the following actual works' record :—

CHARGE TIME SHEET.

Charged into Converter.		9-30 a.m.
Analysis of (pig and scrap) = 1 ton.		
Total carbon	3·00%	
Silicon	2·20%	
Sulphur	0·03%	Soda ash treatment.
Phosphorus	0·03%	
Manganese	0·80%	
Charge blown.		10-0 a.m.
Analysis.		
Carbon	0·09%	
Silicon	0·01%	
Sulphur	0·033%	
Phosphorus	0·033%	
Manganese	Trace	
Additions—(cold) Ferro manganese, ferro silicon, nickel, chromium, etc.		
Arcs operating.		10-5 a.m.
Bath ready for tapping		10-20 a.m.

Two furnaces may be operated by installing one unit of the electrical arc gear in the centre, or each furnace may be used on alternative days to enable refractory repairs.

This combination plant could be used solely, if desired, for melting metals and alloys from the cold. The arcs may be used for melting and the reduction completed by air. In other words, this is similar to the stock-converter process, but replacing oil melting by the introduction of electric arcs.

The electrical equipment for this combination furnace has been especially designed, and the complete plant, which is patented, is suitable for the economical production of quantities ranging from half a ton up to about three tons capacity per hour, either in carbon steels, alloy steels, or special cast irons.

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INCORPORATING "THE METALLURGICAL ENGINEER"

Metallurgists and the Forces

FROM correspondence we have received, there seems to be doubt in the minds of some readers regarding their duty under present conditions, due to a desire for more active participation in the present hostilities. Several seem to be quite dissatisfied with their present position and to feel that they are not pulling their weight.

It is assumed that those who have sought advice are young men under the age of 25, and one in particular had taken the matter up with the manager of his firm, who advised him that should he join the Forces immediate steps would be taken to obtain his release to continue the work upon which he is at present engaged. There must be many others who have asked themselves whether they are justified in carrying on their scientific and technical duties while many of their friends are in the Forces.

To all in doubt on this point, we have no hesitation in saying that metallurgists are of greater value to this country in the particular branches for which they are specially trained. Many mistakes were made in recruitment for the armed Forces in the Great War of 1914-1918, with the result that scientifically and technically trained men available on the home front were insufficient to meet the demand for their services. In several instances qualified men in the armed Forces were returned to industry.

Fortunately, the lessons from that war have been appreciated, and much greater care is being exercised to preserve scientifically and technically trained men for duties which are of more vital importance than would be imposed upon them as members of the armed Forces. It should not be overlooked that with an expanding army, navy and air force, there is not only need for increased personnel in these forces, but also for supporting units and for armament and munition manufacture. The war machine to-day is so highly mechanised that science and technology are essential to its successful maintenance.

Since our correspondence with several readers on the subject, we have been in communication with the President of the Institute of Metals, Dr. C. H. Desch, who, with his unfailing courtesy and helpfulness, has sent the following message to readers :—

" Some metallurgists appear to be in doubt as to the way in which they can render the best service to their country, feeling perhaps that the work on which they are engaged is unimportant in comparison with that of defence. In considering such a question, which causes real searchings of heart among earnest citizens, account must be taken of the nature of modern warfare. Whether on land or sea or in the air, fighting is now carried on with mechanisms of great complexity, in the form of guns, ships, aircraft and tanks. All of these are metallic structures, and are used under conditions calling for the highest possible mechanical properties in their materials. The unexpected failure of a single part may be disastrous. Hence, whilst the production of metals and alloys has to be accelerated during war-time, the strict control of their quality becomes increasingly important, and the skilled metallurgist takes his place as an essential factor in the defence of the nation.

" The research worker, although he may have reluctantly to abandon for a time a programme of long range and turn to some more immediate problem, finds himself called on to investigate difficulties in production, to examine the cause of failures, or to assist in the development of some new device or process. He may be disappointed at first by the apparent lack of need for his services, since time is needed for the complete adjustment of industry to war conditions, but there need be no fear of a diminished demand for metallurgists. Rather we shall be brought to realise that the supply of trained metallurgists in recent years has fallen short of what is desirable, and that difficulty may be found in meeting all the requirements of industry for men with the necessary experience. The Central Register is intended for this purpose, and it is to be hoped that all metallurgists who read this have already filled in their cards, so that their records are available. In the meantime, most of them will be rendering the greatest service by remaining in their present posts.

"A further word may be added. Studies are unavoidably interrupted or carried on under more difficult conditions. This is not a time, however, in which to lose touch with scientific and technical progress. For some, direct acquaintance with what is being done in the branch of science with which they are concerned actually becomes more essential. Herein lies the value of membership of technical institutes which provide publications, libraries, and access to sources of information on technical matters. Metallurgical periodicals assume an increased importance. The Iron and Steel Institute and the Institute of Metals maintain a joint library, which is kept open for the use of their members, and there is no interruption in their information service. The Institute of Metals will continue the publication of its Monthly Journal and Abstracts, and the experience of the last war, during which its membership increased greatly, is likely to be repeated."

Even after reading this message, some may feel that the work on which they are at present engaged may not appear to them to be of sufficient importance to be regarded as essential in this national emergency, and in order that their services may be applied in the most useful channels, we direct their attention to a special notice concerning the voluntary recruitment of men with scientific and technical qualifications. It refers to men under the age of 25 who wish to enlist in H.M. Forces, and advises them to apply to any local office of the Ministry of Labour for a special form which should be completed and returned as directed.

These forms will be referred to special Technical Committees which have been established at the Universities. This will ensure that men possessing certain qualifications are allocated to forms of National Service in which they will be the most useful. The following classes of men under the age of 25 are affected by these arrangements :—

(*a*) Men with University degrees in any of the following subjects : Engineering, chemistry, metallurgy, physics, the biological sciences (including agriculture), and mathematics (including statistics) ; (*b*) men with Higher National Diplomas or Higher National Certificates in mechanical and electrical engineering ; (*c*) men who have started or are about to start their final year's study for one of the following degrees : an honours or pass degree in engineering, or an honours degree in chemistry, metallurgy or physics ; (*d*) men who have started or are about to start their final year's study for the Higher National Diploma or High National Certificate in mechanical and electrical engineering, or for the Associateship of the Institute of Chemistry.

Research in Steel Metallurgy

The Sheffield Metallurgical Association has arranged a very interesting lecture programme for the session 1939-40. That the educational value of these lectures will be of a high order will be appreciated from the names of lecturers in the programme, which include Dr. W. H. Hatfield, Prof. J. H. Andrew, Prof. Swift, and Dr. T. Swinden. The Association is to be congratulated on the decision to maintain its activities and on the excellent programme arranged.
The first lecture in the series was given on October 31, by Dr. W. H. Hatfield on the above subject, and we are indebted to the Hon. Secretary, Mr. L. Rotherham, M.Sc., for the following brief review of the lecture.

IN his opening remarks, Dr. Hatfield expressed his satisfaction at being able to open the present programme of lectures, and pointed out that he was the first President of the Association when it began activities during the last war. He congratulated the Association on its resumed lecture programme.

It is well known that during the last war many marked advances in metallurgy were made, and it is apparent that with the extended research facilities now available, the same result should be possible during the present war, and, in fact, if the position of our country is to be maintained, the progressive development of fundamental knowledge and its application to industry must continue throughout the war. This will also help us to meet the severe conditions we may expect after the war.

Scientific workers may be divided into two classes. Of these, those engaged in industry apply scientific methods to the solution of every-day problems in addition to trying to extend knowledge in general. On the other hand, the Universities and National Laboratories carry out more purely scientific work and are detached from any need to apply their work in any particular industry. It is unnecessary for them to have any specialised experience of industry, but the industrial worker must be able to draw from the work of the pure scientist. The Scientific Associations provide a common meeting ground for the different classes of workers, and play a valuable part in the dissemination of ideas and information.

Dr. Hatfield uttered a protest against the use of men with special scientific training being included in the fighting forces in occupations where their knowledge might be wasted. It was better to apply them to their own field of study.

Since the last war, the production of corrosion-resisting, heat-resisting and magnet steels, to name three examples, has progressed enormously, and there is every promise that the next 25 years will be equally fruitful, always providing facilities and men are available.

Ingot Research

A colour film of steel-melting processes, produced by Dr. Hatfield's assistant, Mr. L. G. Earle, was shown, giving the different processes from melting an experimental ingot of 50 lb. in a laboratory high-frequency furnace to the casting of a 220-ton ingot of open-hearth steel.

The understanding of segregation phenomena has helped very greatly to facilitate the production of very large ingots. This work has been carried out extensively by the Ingot Committee of the Iron and Steel Institute. The work has been very costly to the co-operating firms and very extensive, and although much work is still being done, the results obtained are already of great importance.

The zone of segregation of the alloying elements and segregated impurities was indicated for large masses, but of particular interest a slide showing a sulphur print of an ingot of a steel used in aeroplane manufacture indicated the very high degree of purity now possible in ingots of 15 cwt.–1 ton, using the best modern technique.

Heat-resisting Steels

Another field of modern research activity where much progress has been made is in the production and development of heat-resisting steels. In all research activities it is difficult to extrapolate from short-time tests to the long periods encountered in service. A creep test at room temperature was illustrated which establishes that for all practical purposes the dimensions of the sample under test are permanent. The sample under test is a cold-worked austenitic steel strip with a yield-point of 29 tons/sq. in. This steel has been stressed for 11 years at 25 tons/sq. in., and it has been established that the rate of deformation is less than $\frac{1}{30{,}000{,}000{,}000}$ in./in./hr.

On the other hand, the deformation at elevated temperatures may continue for long periods. This was illustrated by a creep curve on a heat-resisting steel at 900° C. The test was maintained for 10,000 hours, and the creep rate was observed to decrease over the first 2,000 hours of test. From this time until the end of the test a steady creep rate was obtained. The very extensive battery of creep machines at the Brown-Firth Research Laboratories on which tests of this sort are made was illustrated.

The exposure for the 10,000-hour period at 900° C. under stress causes considerable changes in the micro-structure of the material, particularly on the surface. The modifying effect of the stress imposed is not fully understood, and requires further investigation. The micro-photographs indicate that the scaling at the temperature of 900° C. is not continuous, and this is substantiated by the fact that the creep rate remains steady over a long period. We have reason to believe that the scale is formed early in the test and protects the material against further oxidation.

Another example of a long-time test at elevated temperatures was the effect of 13 months' exposure to 450° C. on the microstructure of mild steel. The tests, which are in accordance with many others carried out in the same laboratories, show no trace of spheroidisation of the carbide in the pearlite.

Corrosion Tests

The work of the Corrosion Committee of the Iron and Steel Institute was briefly reviewed. Very many corrosion stations are maintained in different parts of the world, and the type of station was illustrated by photographs of the very extensive corrosion station at Attercliffe. At these stations the various samples are exposed to the weathering action of different climatic conditions. The results obtained will soon be reviewed more completely in a publication by Dr. Hudson.

A particularly interesting experiment was described in more detail. In 1924 a number of samples were placed in bottles of various reagents, including 1.20 S.G. nitric acid. In 1928 it was found that the sample in the nitric acid had become slightly discoloured and a second sample was placed in nitric acid. In 1931 a third sample was inserted, and all three samples show evidence of discolouration.

It has been calculated that the thickness of the film on the samples varies from $6{\cdot}5 \times 10^{-6}$ cms. on the 1924 sample to $4{\cdot}9 \times 10^{-6}$ cms. on the 1928 sample, and $2{\cdot}1 \times 10^{-6}$ cms. on the 1931 sample. From these results it is obvious that the film thickens with time in this particular reagent. The subject is one which would provide a subject for profitable discussion at a later date.

Nickel Additions to High-Purity Copper

Torsional Properties

By W. F. Chubb, Ph.D., B.Sc.

The effects on torsional modulus and rigidity by small additions of nickel to copper of high purity have been investigated. The methods employed are described, and the results discussed. It is suggested that torsional measurements of a high degree of accuracy would lead to a fundamental relationship between modulus of rigidity and composition.

A GOOD deal of research work has been done in the past decade on the influence of impurities upon the properties of pure metals and alloys. These researches would appear to have arisen primarily from commercial experiences showing that even in small amounts an additional element in otherwise pure material may sometimes appreciably affect its behaviour in service. Of the properties which have been most frequently studied, mention may be made of castability, density, hardness and tensile strength, and these properties have been examined chiefly because their relationship to manufacturing processes is direct. Yet in considering service requirements in a very large number of industrial applications there is one fundamental property which is not too frequently examined, and which is in some instances neglected entirely, that being the behaviour of metals and alloys under stresses of a torsional character. Indeed, if the available literature be scrutinised carefully, it will be clear that very little is known as to the effects of small additions of impurities upon the torsional behaviour of pure metals and alloys. This is not, of course, a problem which will directly affect manufacturing methods and technique, and this fact may indeed be sufficient to explain the dearth of information on so important a subject. It has for this reason been of some interest to examine in the course of a lengthy research into the influences of small additions of nickel to copper of high purity the effects produced upon the torsional modulus and rigidity, and it is the purpose of this short article to describe the methods employed and discuss the results obtained.

Test Bars

In the preparation of suitable alloys, casts were made containing a maximum of 0·5% of nickel, the basic materials employed being cathode copper and nickel shot of the following analyses :—

A—COPPER.

	%
Nickel	Nil
Iron	0·0045
Lead	0·0035
Tin	Trace
Zinc	Trace
Oxygen	0·026

B—NICKEL.

	%
Iron	0·040
Copper	0·020
Sulphur	0·011

The analyses of the alloys so prepared are quoted in Table I.

After casting these materials as 1-in. round chill rods, the required alloys were rolled hot to ½ in. diameter and then cold-drawn to ¼ in. diameter in two stages with intermediate pickling and cleaning, and were then annealed at 630° C. for 1 hour in a gas-fired furnace, being quenched from that temperature in cold water. For the torsional measurements, specimens each 8 in. in length were parted off.

Apparatus

For the measurement of the torsional properties of these alloys an Amsler machine was available, and since certain modifications were desirable some description of this machine may be included.

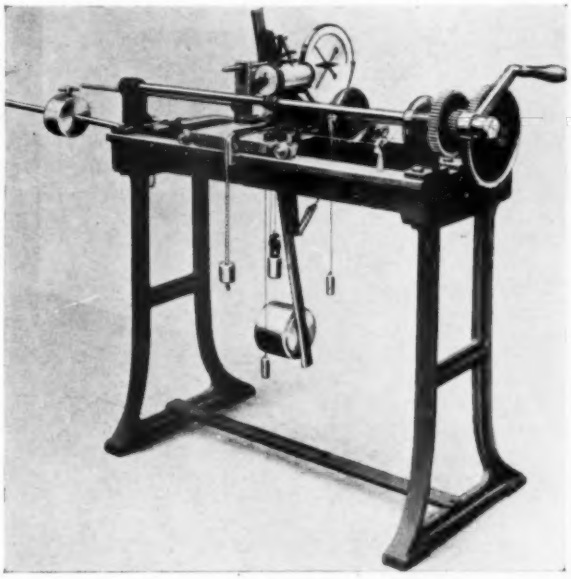


Fig. 1.—Showing the Amsler machine employed.

The Amsler torsion-testing machine is made in several types, depending upon the range of the measurements

TABLE I.

ANALYSES OF THE ALLOYS.

Specification.	Specimen No.	Oxygen %	Nickel %	Iron %	Lead %
(A) *High-Oxygen Series*—					
Nickel absent	5	0·106 0·106	Nil	0·0040	0·0021
„ 0·1%	3	0·065 0·067	0·107	0·0040	0·0021
„ 0·2%	6	0·067 0·067	0·204 0·204	0·0038	0·0014
„ 0·3%	8	0·084 0·083	0·303 0·302	0·0033	0·0015
„ 0·5%	11	0·073 0·071	0·508 0·508	0·0033	0·0013
(B) *Low-Oxygen Series*—					
Nickel absent	1	0·026 0·025	Nil	0·0045	0·0033
„ 0·1%	2	0·029 0·027	0·106	0·0042	0·0033
„ 0·2%	7	0·025 0·023	0·204 0·204	0·0037	0·0014
„ 0·3%	9	0·021 0·023	0·303 0·303	0·0042	0·0014
„ 0·5%	10	0·016 0·014	0·508 0·507	0·0038	0·0013
Additional copper specimen	4	0·036	0·006	0·0042	0·0011

desired, and the machine of the type employed in the present instance is illustrated in Fig. 1. Here the principal details may be seen. The specimen is gripped between toothed wedges in gripping heads, the distance between them being adjustable over a range of zero to 14 in. In the particular experiments undertaken the specimens inserted were 8 in. in length, the gauge length between the torquemeter arms being 6 in. In the original machine one gripping head was capable of being rotated by hand, thereby twisting the test-piece, and a simple arrangement of gears allowed this head to be rotated either quickly or slowly, as required. Since, however, investigations within the elastic range were primarily sought, a still slower rate of twisting was required, and for this purpose a hand-operated worm-and-wheel reduction unit giving a 10-to-1 reduction was attached.

The other gripping head is fitted to the axis of a pendulum which carries an adjustable weight at its lower end. When the specimen is twisted this second gripping head is also set in motion, the pendulum being thereby raised from its vertical position until the deviating couple balances the applied twisting couple. The inclination of the pendulum thus provides a measure of the torsional moment applied, the latter being transmitted to a pointer which records the movement on the revolving drum. Before use, this drum must, of course, be accurately calibrated.

It will be clear that since the deviating couple of the pendulum depends upon the weight of the pendulum and upon the height of its centre of gravity, the sensitivity of the machine may be varied conveniently. In the machine available this adjustment gave a sensitivity over a torque range of 4·8 to 48 ft.-lb. The autographic recording attachment provides means also for measuring the number of twists suffered by the specimen at fracture.

The pendulum and recording apparatus are mounted on a carriage which may be moved along the machine to suit the length of the specimen under test, and means are provided also for applying axially to the test-piece a small and predetermined load to keep the specimen in tension throughout experimental measurements.

Calibration

The supplementary apparatus for calibration supplied with this machine consists of a well-balanced lever of known length which is attached to the gripping head carrying the pendulum. After adjustment of the pendulum to the desired sensitivity, calibrated weights are applied to a pan suspended from the end of the balancing lever and the movement of the pendulum across the drum scale is measured for increasingly applied torque. In this manner the following calibration of the machine was secured before undertaking the measurements required, the length of the balancing lever being 19·72 in.

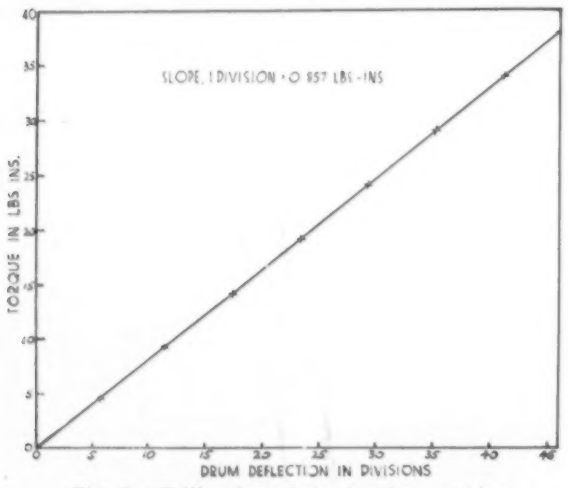


Fig. 2.—Calibration of the Amsler machine.

Weight in Lb.		Torque in Lb.-In.		Drum Scale Division.
0	....	0	....	0
0·25	....	4·88	....	5·7
0·50	....	9·77	....	11·4
0·75	....	14·72	....	17·2
1·00	....	19·72	....	23·0
1·25	....	24·68	....	28·8
1·50	....	29·74	....	34·7
1·75	....	34·54	....	40·3
2·00	....	39·42	....	46·0
1·75	....	34·54	....	40·3
1·50	....	29·82	....	34·8
1·25	....	24·76	....	28·9
1·00	....	19·72	....	23·0
0·72	....	14·74	....	17·0
0·50	....	9·77	....	11·4
0·25	....	8·85	....	5·7
0	....	0	....	0

From these calibration figures, plotted in the accompanying graph of Fig. 2, a torque of 39·42 lb.-in. provided a drum deflection of 46·0 small divisions, or each division corresponded to an applied torque of 0·857 lb.-in.

Torquemeter

A torquemeter suitable for use when exceptionally high accuracy is not required may consist of two stout steel arms each firmly screwed into a collar for attachment to the specimen by means of a set-screw. A convenient length is about 12 in. measured from the axis of the specimen, the exact length in the present series of experiments being 12·03 in. A portion of steel scale divided into hundredths of an inch and bent to the above radius may be affixed suitably to one of these arms, the other arm being of similar length but bent at an appropriate distance from the axis of the test-piece to form a length parallel to it and with the extreme end of this parallel portion abutting the scale. To facilitate accurate readings of twist, this arm should be tapered to a knife-edge by grinding. The divided scale attached to the other arm was in this instance 3·5 in. in length, it being calculated that when using specimens of ¼ in. diameter this length should be sufficient for measurements within the elastic portion of the stress-strain diagram.

Results

Table II shows for these copper-nickel alloys the full details of all the measurements made, and Fig. 3 gives the stress-strain diagrams traced from the actual authographic records. From the latter have been measured as accurately as possible the torque values at the limit of proportionality and the corresponding stress, f_s, in lb. per sq. in. has been calculated, using the well-known formula—

$$f_s = \frac{16\,M_t}{\pi\,d^3},$$

where M_t is the measured torque in lb.-in., and d is the diameter of the specimen in inches.

Over the elastic portion of the curves taken, the recorded values of torque and corresponding twist serve for the calculation of the torque per radian of twist, and this value may then be employed in each instance for deducing the modulus of rigidity, using the established formula for a solid specimen—namely,

$$G = \frac{18 \times 32 \times M_t.l}{\pi^2.O.d^4}$$

in which M is the torque in lb.-in. for a corresponding twist of O°, l is the gauge length of the specimen, and d its diameter in inches. All the most important properties within the elastic limit of each alloy specimen have been included in Table II, and to complete the observations the equivalent stress in tons per sq. in. at fracture has been calculated also in each instance.

From these results, plotted in Figs. 4 and 5, it will be seen that for the series of alloys containing a lower percentage of oxygen there has been, with addition of nickel, a progressive increase in all the properties, both measured and calculated, within the range of composition here covered. The curve relating to the torque per degree of twist is not, however, a straight line, nor does that representing the calculated stress at fracture appear to

TABLE II.—TORSIONAL PROPERTIES.

Specification.	Alloy.	Limit of Proportionality.		Torque at Fracture, In.-Lb.	Turns at Fracture.	Torque per Radian, Lb.-In.	Calculated Stress at Fracture, Tons/Sq. In.	Rigidity Modulus, $G \times 10^6$, Lb./Sq. In.
		In.-Lb.	Lb./Sq. In.					
(A) *High-Oxygen Series*—								
Ni. nil, (0·106% oxygen)	5	16·0	5,299	102·91	25·98	355·6	14·11	5·31
„ 0·107% (0·066% „)	3	16·8	5,284	101·13	21·00	355·3	14·20	5·34
„ 0·204% (0·067% „)	6	20·1	6,247	102·80	23·15	391·5	14·25	5·75
„ 0·303% (0·084% „)	8	21·5	6,762	111·97	43·14	412·2	15·72	5·96
„ 0·508% (0·072% „)	11	23·5	7,399	109·98	29·90	420·8	15·16	6·16
(B) *Low-Oxygen Series*—								
Ni. nil (0·026% oxygen)	1	16·0	4,914	95·43	15·80	354·6	13·09	5·21
„ 0·106% (0·028% „)	2	17·1	5,318	97·87	20·90	364·2	13·58	5·39
„ 0·204% (0·024% „)	7	19·0	5,975	105·58	33·64	390·3	14·82	5·64
„ 0·303% (0·022% „)	9	20·6	6,479	106·64	30·16	404·3	14·97	5·84
„ 0·508% (0·015% „)	10	22·4	7,003	102·84	34·26	416·1	14·35	6·08

provide a straight-line relationship to composition, but the modulus of rigidity, a more fundamental property involving test-piece dimensions, provides a smooth curve. This is also not a straight-line relationship, though very nearly so. Similar results are to be seen in regard to the measured proportionality limit and the calculated stress corresponding to it, the latter giving a very nearly straight line over the range of 0 to 0·306% of nickel.

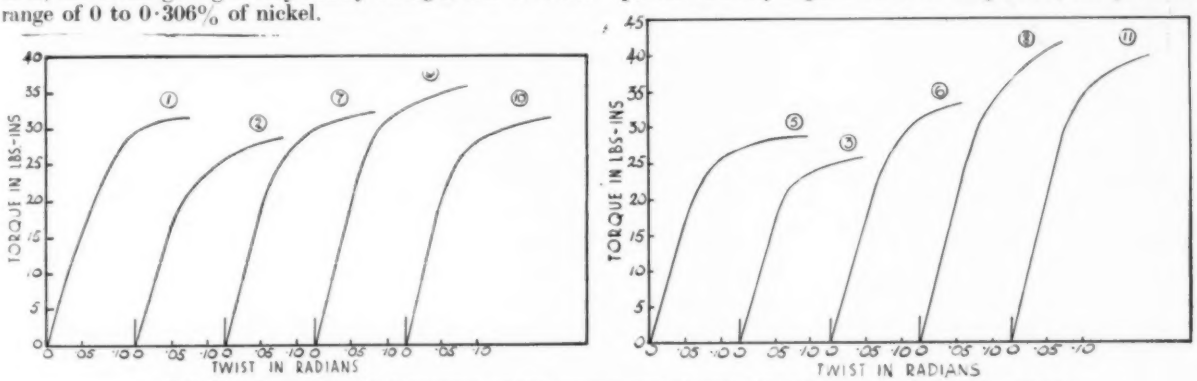


Fig. 3.—Stress-strain diagrams of the copper-nickel and the copper-nickel-oxygen series.

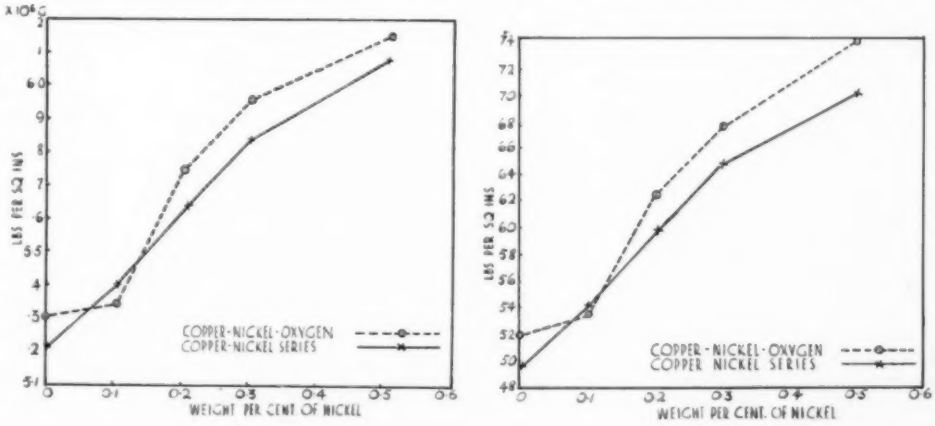
From the individual figures certain broad deductions appear warranted, for by alloying with 0·508% of nickel the limit of proportionality has increased by 2,089 lb. per sq. in. in the low oxygen series of alloys, an increase of 42·5% over the original value in the alloyed specimen. In a similar manner, the modulus of rigidity G has risen from 5·21 to 6·08 × 10^6 lb. per sq. in., or by 16·7%. These values correspond to increases of 4,110 lb. per sq. in. in the limit of proportionality and to an increase of 1·71 × 10^6 lb. per sq. in. in rigidity modulus by alloying with 1% of nickel. The curve suggests, however, that these rates of increase in each property are not likely to be maintained upon further addition of the alloying element, but it is not possible to decide the form which these curves would then assume.

As regards the calculated stress at fracture, the results show a general though disproportionate increase by addition of nickel up to 0·306%, although a further addition of 0·202% of that element appears to have lowered this property to some extent. However, over the first range of composition mentioned the average rate of increase amounts to 1·88 tons per sq. in., or about 14·3% of the original value for unalloyed copper.

Turning to the series containing higher percentages of oxygen, a similar general behaviour is found throughout the specimens in regard to the properties of proportionality limit and modulus of rigidity. These measurements provide a fairly regular curve when plotted, except that in each instance specimen No. 3, containing an exceptionally high oxygen content of 0·106%, has properties somewhat inferior to those expected.

From the individual results it is found that over the whole range the calculated stress at the proportionality limit has increased by 2,091 lb. per sq. in.—that is, by 25·4% of the initial value for copper containing no nickel. The more fundamental property of rigidity modulus increases from 5·31 to 6·16 × 10^6 lb. per sq. in., or by 16·0% in these specimens, an increase which it will be observed is of the same order as that found in the low-oxygen series.

Fig. 4.—Torsional properties—
Modulus of rigidity. **Limit of proportionality.**

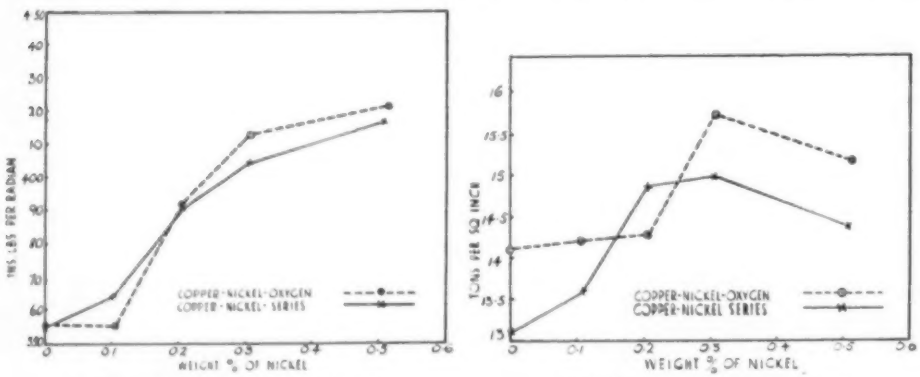


In making comparisons between these two series, corrections must clearly be made on account of varying oxygen contents, and these corrections are essential in any attempt to deduce a general formula showing the relationship between modulus of rigidity and composition. When the limiting values for each series are detailed, as in Table III below, certain deductions as regards the influence of nickel and oxygen appear to be justified.

TABLE III.

Specimen No.	Nickel, %	Oxygen %	G × 10^6, Lb.-In.
10	0·508	Nil	6·08
1	Nil	0·026	5·21
11	0·508	0·073	6·16
5	Nil	0·106	5·31

In the first place, the pure copper specimen of low oxygen content—that is, specimen No. 1—contains 0·026% of that element, and the corresponding specimen in the oxygen-bearing series—namely, No. 5—contains 0·106% of oxygen. This difference in oxygen content, amounting to 0·080%, corresponds to a difference of 0·10 × 10^6 lb. per sq. in. in rigidity modulus. Assuming that this increase is proportional to oxygen content, a computation of the modulus of rigidity for copper containing no oxygen may be considered justified, and this is accordingly calculated to be 5·18 × 10^6 lb. per sq. in. Similarly, to render specimen No. 5 comparable with specimen No. 2 in the high oxygen series, it is necessary to reduce the rigidity modulus of specimen No. 5 to a value corresponding to an oxygen content the same as that of specimen No. 2. These calculations then provide the theoretical values of rigidity modulus details in Table IV., in which the suffix " CT " indicates a " Calculated Theoretical " value.



Torque/twist within elastic limit. Calculated stress at fracture.

Fig. 5.—Torsional properties.

TABLE IV.

Specimen No.	Nickel, %	Oxygen, %	G × 10^6 Lb.-In.
10	0·508	Nil	6·08
1 CT	Nil	Nil	5·18
Difference	0·508	Nil	0·90
11	0·508	0·073	6·18
5 CT	Nil	0·073	5·28
Difference	0·508	Nil	0·90

This treatment of the results thus leads to the suggestion that the influence of either of these two elements, nickel and oxygen, on the rigidity modulus of copper has little or no effect upon the influence exerted by the other. It would also appear that in the case of the torsional properties the individual effects of these two constituents are additive over the ranges examined. Before this can be established with certainty, however, it would seem desirable to measure these influences with a much higher degree of accuracy than has been possible with the simple methods employed here, the calculated accuracy of the measurements being 1%. An attempt has nevertheless been made to advance from the observed results a formula connecting modulus of rigidity with composition. Thus, from the details previously tabulated it is found that addition of 0·106% of oxygen to oxygen-free copper increases this property by 0·13 × 10^6 lb. per sq. in.—that is to say, by 1·23 × 10^6 lb. per sq. in. for an addition of 1% of oxygen. Similarly, a comparison between specimens Nos. 10 and 11 shows an increase in the value of rigidity modulus amounting to 1·09 × 10^6 lb. per sq. in. for an addition of 1% of oxygen to oxygen-free copper, or an average of 1·16 × 10^6 lb. per sq. in.

In a similar way, it is calculated that 0·508% of nickel corresponds in each series to an increase of 0·90 × 10^6 lb. per sq. in. in the rigidity modulus, or to 1·77 lb. per sq. in. for every 1% of nickel added. Hence, from these computations the modulus of rigidity G of any specimen within the ranges examined may be expressed according to the following formula :—

G in 10^6 lb. per sq. in. = 5·18 + (1·77 × % nickel)+ (1·16 × % oxygen).

Check calculations employing this formula provide values of rigidity modulus which are within the stated limits of accuracy of the original measurements.

This formula must of necessity be regarded as purely empirical. A mathematical analysis of the graphs constructed would serve no useful purpose, but it would seem clear nevertheless from these measurements that torsional measurements undertaken to a much higher degree of accuracy than has here been possible would probably lead to the establishment of a more fundamental relationship between modulus of rigidity and composition.

British Standard Specifications

Abrasive Papers and Cloths

BRITISH Standards have just been issued dealing with Abrasive Papers and Cloths. The specifications have been grouped into two reports, one dealing with what are known in the trade as " Technical Products," and the other with papers and cloths for general purposes.

The specification for technical products provides for abrasive papers and cloths for engineers, wood working, rubbing down filler, and paint and lacquer surfaces, and general utility work. This specification covers flint papers, silicon carbide papers, garnet papers and aluminium oxide metal-working cloth.

The specification for general purposes includes emery cloth, glass paper, glass cloth, flint paper, and flint cloth.

It has not been found possible at this stage to include a comprehensive test for the quality of the finished product, as there is insufficient data available to form the basis of test requirements. Experiments are being made and the subject will be given further consideration when, in due course, the specifications come up for revision.

In view of the fact that it is not possible to specify grading requirements for the abrasive and since it was felt that no special advantage would be gained by the provision of cards to illustrate the grading on each specification, it has been decided, for reference purposes, that coated samples and samples of standard sands shall be deposited at the Offices of the Institution.

Copies of these Specifications, Nos. 871 and 872, are obtainable from the British Standards Institution, Publications Department, 28, Victoria Street, London, S.W. 1, price 2s. net, or 2s. 2d. each, post free.

The Use of Aluminium Alloys in Aircraft

W. C. Devereux, F.R.Ae.S., M.Inst.Met.

An effort is made to assess the application by aircraft designers of aluminium alloys at their disposal; to determine to what extent materials available are in advance of stated requirements and to form conclusions on the directions in which research and development by aluminium alloy manufacturers may be concentrated. This paper was prepared for presentation at the Second Aluminium Congress at Zürich, which could not be held on September 12-14 last as arranged, owing to the outbreak of war.

THE present is an opportune time for examining the position of aluminium alloys in their application to aircraft. The last few years have seen a tremendous growth in the production of aeroplanes; it is only now that one can properly assess the use that aircraft designers are making of the alloys at their disposal, obtain a true indication of the direction in which the materials available are ahead of the stated requirements, and form some conclusion on the direction in which research and development by the aluminium alloy manufacturers may best be concentrated.

Up till 1937 delays which occurred between the completion of a design and the production of aircraft going into service, often running into several years, meant that the design of an aeroplane just going into service was representative of light alloy practice perhaps as many as five

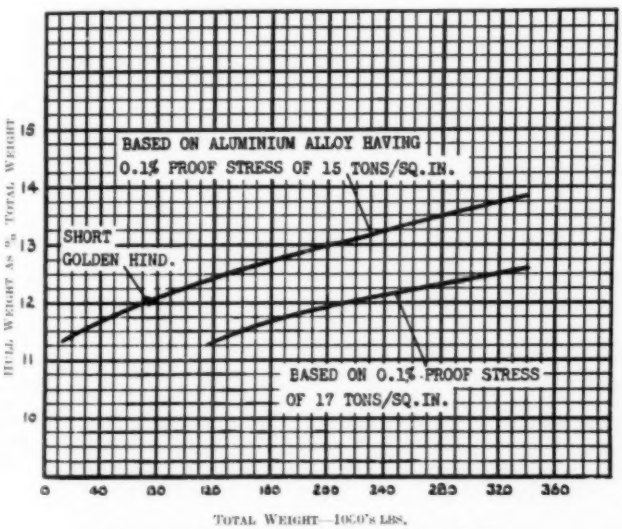


Fig. 1.—The weight of flying boat hulls.

years past. Those persons in contact with the development of light alloys will know that a lapse of five years may see radical changes in light alloy engineering. It is interesting, therefore, at the present time to be able to examine a number of predictions made by eminent aeronautical engineers a few years ago, and to examine aeroplanes, in service at the moment, in an attempt to find out to what extent light alloy engineers have been able to comply with the demands made on their ingenuity.

In a paper I read in 1937, entitled "The Future Trend of Light Alloys," I drew attention to a prediction made by Gouge, of Short Brothers, in which was shown the reduction in the hull weight of a flying boat that could be expected from an increase in the proof stress of aluminium alloy sheet of 2 tons per sq. in., from 15 to 17 tons per sq. in. The weight reduction expected was 8·6% of the weight of the bare hull. Thus, in the case of a flying boat, such as the Short Sunderland, having an all up weight of 45,700lb. an increase in disposable load of 480 lb. might be expected. Again, it is interesting to note that in November, 1937, High Duty Alloys introduced to the aircraft industry Hiduminium RR 77. Available in extruded and sheet form, this alloy has a 0·1% proof stress of 28 tons per sq. in. Thus two years have elapsed since a sheet material became available having a proof stress of 13 tons per sq. in. higher than that used by Gouge in 1935, when he mentions that a sheet having a proof stress of 17 tons per sq. in. had just become available.

Assuming that a weight reduction on the weight of the bare hull of 8·6% can be achieved continuously for every 2 tons per sq. in. increase in proof stress, then the weight of the hull of a flying boat designed after 1937 might be expected to weigh only 44% of one designed prior to, or up to, 1935, representing in the case of the Short Sunderland an increase in disposable load of 3,120 lb. due to lightening the hull only. Further, assuming that in the case of a flying boat, a considerable proportion of the tare weight is made up of sheet materials, we may obtain a rough estimate of the possibilities of similar weight reductions throughout the structure. Let us assume that 30% of the all-up weight of the boat is in the structure, then the weight of the material in a boat weighing 45,700 lb., to which we may make the drastic reduction of 56%, is 13,710 lb., and the weight saved will be 7,680 lb. If this weight saving could be achieved in practice we would have a flying boat of all-up weight 45,700 lb., tare weight 20,610 lb., disposable load 25,090 lb., which for a military flying boat would be remarkable indeed, instead of tare weight 28,290 lb. and disposable load 17,410 lb.

The most conclusive argument that I am able to present in order to show that these predicted weight reductions have not been achieved is a brief examination of the most recently completed of the Short flying boats, the *Golden Hind*, all-up weight 73,500 lb. and hull weight 8,800 lb., or 12% of the all-up weight. In Fig. 1, which is a reproduction of a slide shown by Gouge in 1935 to illustrate the expected weight reduction, it will be noted that for the *Golden Hind* the fuselage weight lies exactly on the line indicating the use of sheet material having a proof stress of only 15 tons per sq. in., not even the first weight reduction, that expected from an increase of only 2 tons per sq. in. having been achieved. In analysing the reasons for this, it is necessary to delve into several different aspects of aircraft design; the most important falling under three headings.

In the first case, let us consider the stress-carrying capacity of the sheet panel and its supporting structure. It is not immediately apparent to engineers not intimately in contact with problems of aircraft design that the thinness of materials used in monocoque construction make the elastic stability of the materials used of far greater importance than the strength of the materials themselves. Without delving too deeply into the theories involved, it is sufficient to say that in monocoque designs the proof stress of the materials does not become a matter of importance until the size of the aircraft increases to the stage when the thickness of plating used precludes all considerations of elastic instability or secondary failure of the plate

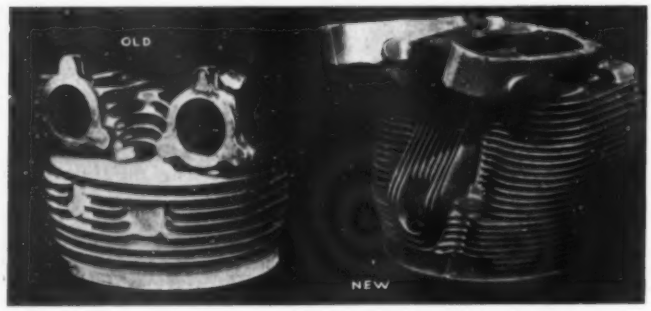


Fig. 2.—A comparison between sand-cast cylinder heads.

at an average stress lower than the proof stress. This condition is not achieved in aeroplanes of the size in use to-day.

Secondly, the great increase in the speed of aeroplanes achieved in recent years has necessitated an alteration in the requirements of aircraft structures. Whereas in the period up to 1935 or thereabouts it was sufficient to design a structure having sufficient strength to carry the loads involved, it is now almost true to say that strength is of secondary importance, and that a structure that is stiff enough to ensure reasonable deflection of the wings and tail and to preclude any possibility of flutter at the high speeds attained, is likely to comply with all the strength requirements.

This brings me to a third point, which I believe is seriously limiting the usefulness of high-strength light alloy sheet—that is, the possible strength, or rather lack of strength, of sheet-to-sheet joints.

It is now a steadily increasing practice to use rivets of the work-hardening aluminium magnesium alloy type in order to simplify production, by avoiding the necessity for a constant supply of heat-treated Duralumin rivets and the attendant need for refrigerator storage, but by making this saving in the shops, a certain amount of strength is lost in the joint. However, let us consider for a moment present conditions with regard to riveted joints in high-grade light alloy sheet, using even the stronger Duralumin rivets.

We wish to use an alloy sheet up to its proof stress of 28 tons per sq. in. Twenty gauge (0·036 in.) is a thickness very commonly used in aircraft wings and fuselages, and considering a 12-in. wide sheet of this material, we have at a stress of 28 tons per sq. in. a strength of 27,100 lb. Now a reasonably optimistic figure for the strength of a $\frac{1}{8}$ in. diameter Duralumin rivet in 20-gauge sheet, taking into account the crushing of the rivet and the sheet itself, is 450 lb. Therefore, in order to make the 12-in. joint we need 60 rivets. When one realises that to get a good surface finish on the thin plating of a wing with flush riveting, a rivet spacing of $1\frac{1}{2}$ in. is desirable, and I would say 1 in. the absolute minimum, it will be appreciated that there is considerable difficulty in making a good joint at all, and when made there is a great waste of material weight in a lap joint comprised of five lines of rivets.

Attention is particularly directed to this subject of high-strength aluminium sheet, because I am of the opinion that the aluminium producers are well in advance of the aircraft industry, the users in this field of application of aluminium. Also, because I would like to direct the attention of readers to the need for research on the subject, especially with a view to encouraging a new outlook towards the problem of the jointing of light alloy materials. I think the responsibility may be laid at the door of the producer rather than the user that greater attention has not been paid to this problem at an earlier date, but would like to say that we in England are at present giving the question a great deal of thought and are hoping to be able to publish more useful information in the near future.

Aluminium in Engines

A prediction made in 1935 by Fedden, of the Bristol Aeroplane Co., was that future developments in light alloys would in all probability enable aero engines with a power output of 1,600 h.p. to 1,800 h.p. to be available by 1940. Engines of this horse-power are now becoming available in 1939, and the following figures for both the percentage by weight and volume of light alloys in a few engines are sufficient justification for the belief that the required improvements in the aluminium alloys for aero engines has indeed been achieved.

Fig. 3.—A comparison between forged airscrews.

PERCENTAGE OF LIGHT ALLOYS IN AERO ENGINES

	Liquid Cooled.	Air Cooled.	
Type of Engine.	In Line.	In Line.	Radial.
Percentage of light alloys by weight	47	48·3	53·5
Percentage of light alloys by volume	70·8	74·5	76

Nevertheless, we must keep in mind the fact that even further increases in power output are inevitable, and it is essential for the metallurgist to continue to improve his products to permit these improvements to be made. If engine design is to progress, it is essential for the light alloy industry to produce a better material for pistons. It is, indeed, deplorable, but nevertheless a fact, that those improvements made during the last five years have all been achieved through limiting internal stress by methods of working the materials and modifying the control of heat-treatment. What is needed is a material having a higher specific strength at engine temperatures. After surveying the work done, it is my personal opinion that there is little to expect from the known aluminium alloy system, and that perhaps the solution will be found in the use of a magnesium base alloy.

The sleeve-valve engine has made phenomenal strides, and the improvement in light alloy materials during the past ten years largely brought about its introduction by Fedden, who was alive to the fact that its success would depend on the ability of the light alloy industry to provide the materials required. The introduction of this type of engine has brought about the replacement of steel cylinder barrels by aluminium alloys. The present requirement for both sleeve and poppet valve engines is a successful method of plating the cylinder. Whilst this, as yet, has not been accomplished successfully, great strides have been made.

Larger engines will necessitate larger air-screws, so that the weight of the present type aluminium alloy blades will prove a serious obstacle to larger powers and cause the engine designers, of necessity, to look for other materials for a solution. The difficulty could be overcome by the successful production of a hollow blade in light alloy, and there is to-day more promise of this being brought about than hitherto.

Extrusions

I think it is true to say that in this field we have not

Fig. 4.—A comparison between variable-pitch airscrew hub forgings.

been able to satisfy fully the demands of the aircraft industry. With regard to the strength of the alloys available, I do not think we could be asked for any greater improvements at the moment, especially in view of the remarkably high proof stress to specific gravity ratio of just over ten, achieved in RR 77 extrusions at present being supplied to the industry in quantity. There is, however, a necessity for tapered extrusions and extrusions that vary in section thicknesses. As a problem of production, this is not difficult, and can be said to be solved, but what is wanted is a press designed solely with this idea in view, a costly matter, but one that will have to be faced shortly. With regard to this point, attention may be drawn to the ingenicus methods adopted by aeroplane designers in order to provide a tapering spar boom with the means at their disposal. Some have adopted the expedient of machining a " T " section extruded boom to give a taper in thickness of both the horizontal and vertical portions, while separate machining operations give a taper in both the width and depth of the section.

Castings

Without doubt, the improvements in sand-cast, air-cooled cylinder heads that have been achieved during the past five or six years have been made possible almost entirely by improvements in casting technique alone. With this point in mind, it is interesting to refer to Fig. 2, showing cylinder heads representative of the peak of casting achievement five years ago and to-day.

So rapid is the advance of engine requirements that it is becoming more and more difficult to solve the cylinder head difficulties of the poppet valve engine, and unless better cast materials are forthcoming it will almost certainly be necessary to turn our attention to wrought forms, and much ingenuity is being shown in the methods of stamping for this purpose.

The fact that castings are now used in many parts of an aircraft structure, where hitherto small machined or forged parts have been used, is illustrative of the strides that have been made in this branch of the aluminium industry. A short time ago it was commonly thought that magnesium alloy castings would replace a large number of castings then made in aluminium. I think that this may be so in the case of castings for the air-frame itself, and an interesting example is the Phillips and Powis " Master," a single-engined fighter trainer, of wood construction, which includes 360 separate castings in magnesium alloy, of which 235 are different. However, I think that, as far as the engine is concerned, aluminium will retain its present all-important position.

Forgings and Stampings

The production of parts in large quantities has proved that, with sufficient allowance for tool costs, stampings and forgings, delicate in shape, can be provided to a high degree of accuracy. Fig. 3 shows the development in forged aluminium air-screw blades, made possible by increased tool costs. The blade, which only a few years ago was a clumsy tapered slab, with little shape, is now an extremely accurate full-length stamping, correct for twist and pitch to within $\frac{1}{16}$ in. of finished machined size.

The development in a hub for a variable pitch air-screw is shown in Fig. 4. This part, originally made in one stamping operation, necessitating a considerable amount of material waste and expensive machining operations, is now made in three operations, combining stamping and pressing, requiring three sets of tools, but reducing to a minimum the wastage of metal, and, of course, cutting machining time and cost to a fraction of that originally required.

Sheet Pressing and Drop Stamping

A recently developed technique in the manufacture of small quantity sheet parts has done much to increase the use of aluminium alloy sheet in aircraft design. The use of the drop stamp has brought about a reduction of tool costs for this class of sheet parts and enabled parts to be made readily and quickly, that were previously built up of bent and riveted plate, involving much hand-work. Fig. 5 shows an example of a small angle made by this process. It is noteworthy that the sheet is just stretched deeper than is required, and is subsequently compressed to form the finished angle, so that too great stretching of the material does not occur at the sharp corners.

Fig. 5.—Two stages in the manufacture of a simple sheet part on the drop hammer.

General Considerations

To further the use of aluminium alloys in aircraft design there is yet much research work to be done. In heat-treated materials the effects of heat-treatment must be studied so that they are not lost by development of internal stresses of high magnitude. This study seems to call for three lines of attack :—

(1) The use of heat-treatable alloys in a softer or partially softer condition, which is, of course, an inefficient application of material, but may be successful temporarily.

(2) The design of the component coupled with heat-treatment at a subsequent stage of machining to ensure that internal stresses will be opposed to the direction of the applied forces, and that these stresses will not be disturbed by subsequent machining.

(3) Selective heat-treatment, meaning the insulation of parts of a component during quenching, to ensure that internal stresses will not be additive to applied stresses.

In conclusion, it is my opinion that there is much work to be done apart from the discovery of new alloys. The influences of manipulation and fabrication are so important that much further investigation is necessary. Also the aircraft engineers themselves have much research to do with regard to the correct application of the materials provided for them, calling for increasingly greater co-operation.

Expansion of Non-Ferrous Metal Production in Russia

By A Special Correspondent

A POWERFUL non-ferrous metals industry is being built up in Russia. During the period 1933-37 the output of copper was doubled, and her output of lead was increased more than threefold and of zinc nearly sixfold. Large plants producing other non-ferrous metals, such as aluminium, tin, tungsten, and molybdenum, have sprung up in different parts of the country. Further expansion of the expansion of non-ferrous metals is provided for in the scheme developed for the period 1938-42. By 1942 it is claimed that the production of copper will be increased threefold and of aluminium fourfold, as compared with the output of these metals in 1937. Similar rates of expansion are anticipated for lead, zinc, nickel, tin, magnesium, tungsten, molybdenum and antimony.

There is every indication that these objectives will be achieved as a result of the success of numerous geological parties that have been prospecting for non-ferrous metal deposits over long periods. In Kazakhstan, for instance, large deposits of wolfram have been discovered to the north-west of Lake Balkhash. Molybdenite has been found in the region of Alma-Ata, the capital of Kazakhstan. The nature of the strata gives every reason to believe that the deposits are extensive. In the North Urals big deposits of tin and wolfram ores have been found. Soviet reserves of bauxite have increased considerably as a result of the opening up of large new deposits. It is not surprising, therefore, that in the steppes of Kazakhstan, in Siberia, in the Urals, in the far north and other regions new deposits are being exploited and large non-ferrous metal plants are being erected.

The increase in copper production under the 1938-42 scheme is expected to average 22% per annum. A new copper works, the Greater Jezkazgan, is being built near the rich Jezkazgan deposits in Kazakhstan. A new railway will soon connect Jezkazgan with Balkhash and with Karaganda, both of which sprang into being during the 1933-37 period of development. The Balkhash Works, already in operation, is continually being extended. During the course of the 1938-42 programme its output will be increased fourfold.

Construction of new production units is also continuing at the new copper and sulphur combine in Blyava (South Urals). This combine is expected to be in full operation before 1942. A large copper-smelting combine is also being completed at Revda (Central Urals). In Uzbekistan a large-scale copper industry is also being created. Very large deposits of copper ore have been discovered in the Almalyk mountains, 50 miles from Tashkent, the capital of Uzbekistan. Two hills, the Large Kalmikir and the Small Kalmikir, will be blasted away and mines sunk on their sites. These mines are expected to yield enormous quantities of ore from which the new works will smelt tens of thousands of tons of copper.

Authentic figures for the production of aluminium in U.S.S.R. are not easily obtainable, but in 1937 it was claimed that output ranked as third in the producing countries of the world. According to the scheme arranged for the period 1938-42, the output of aluminium is expected to be increased at least fourfold. A new aluminium works has been put into operation at Kamenskoye, in the Urals. Another aluminium works is under construction in Kandalaksha, at the approaches to the Kola peninsula in the north. This will be put into operation next year. A third aluminium works scheduled for construction will be built in the Kuznetsk Coal Basin in Siberia. This will be the first aluminium works in the Asiatic part of the U.S.S.R.

In 1939 the Soviet Union is stated to have advanced to second world place in respect of nickel production. Among the new big nickel works which have been started this year is one at Monchegorsk, on the Kola Peninsula, and another in the Southern Urals. The Monchegorsk works is situated in a spot which only five years ago was desert tundra. Next year the output of this combine is expected to be trebled. A third large nickel combine is under construction in the district of Norilsk, which is much farther north than Igarka. As a result of all this construction the output of nickel in 1942 is expected to increase twelvefold, as compared with 1937.

The lead and zinc industries have been developed intensely since 1927. In 1937 the production of lead rose by 230%, as compared with 1932, and the production of zinc by 470%. Still further expansion is provided for by 1942 in the production of these metals. New lead and zinc works are being built in various parts of the Union. Of special importance among the new enterprises of the lead and zinc industry is a large combine being constructed in the Altai mountains, where 58% of the lead ore of the U.S.S.R. is concentrated. Since 1927 many works have been constructed in that neighbourhood, and now a very large polymetallic combine is being built there. At the same time, a big hydro-electric power station is going up on the River Irtysh, at the city of Ust-Kamennogorsk, to supply electric energy to the enterprises of this combine. New lead works are now being completed in East Siberia, in Kazakhstan and the Far East, also in Yakutia and other districts of the Soviet Union.

It is noteworthy that a new railway track, 210 miles long, has just been laid, linking one of the largest industrial centres of the U.S.S.R. with the trans-continental lines of Kazakhstan and Asia. Running from Ridder to Rubtsovka, it directly links up the Irtysh copper-smelting works, the Belousov mine, and the Ulbin hydro-electric power station, and also the Irtysh hydro-electric power station, with Siberia; this will greatly conduce to the development of the Ridder Polymetallic Combine, for considerable deposits of non-ferrous metals have been found along its route, and it will serve the needs of the many lead and zinc works now in course of construction.

Considerable attention is being given to development in the production of tin, tungsten and molybdenum. A big tungsten combine is under construction at the Khaltason mountain, rising over the Inkursk Hollow, in the south-west of the Buryat-Mongolian Republic. Wolfram veins intersect the mountain, a large number of which are now being prospected. In these mountains are also considerable quantities of molybdenum bearing ores. In the vicinity of Balkhash, geologists have found substantial deposits of wolfram; big deposits of this ore have also been discovered in the Altai mountains, and rich deposits of molybdenum have been found near Alma-Ata.

Industrial Management and Production Control

Part XI.—Maintenance

By F. L. Meyenberg

The importance of adequate maintenance in the economical functioning of works in the metallurgical industries is emphasised. The author is of the opinion that, from the point of view of manufacturing, administration and control, the maintenance department is often badly treated, and discusses what maintenance means, maintenance orders, limiting repair expenses, spare parts, maintenance programme, wages for maintenance jobs, the machine shop and its equipment, and the clerical system.

WE are coming now, in the course of these articles, to a topic which we may rightly call "a step-child of the metallurgical industry." That is the more astonishing, as the item with which we have to deal is by no means a negligible one. In order to give a figure which may illustrate what is meant by this remark, it may be mentioned that "maintenance" in an iron and steel works of medium size, with an investment of two millions in buildings, roads, machinery equipment, pipe-lines, cables, etc., may perhaps indicate a yearly expenditure of £150,000 and more. And yet how badly is this important department often treated from the point of manufacturing, administration and control. It is not denied that there are pleasing exceptions, but these make the state of affairs in other works more striking.

How can this fact be explained? It is the conviction of the writer that it is the consequence of another fact, which each attentive observer of the metallurgical industry must admit, that the real engineer has comparatively little influence in these works, which could never be developed to their present importance without the indefatigable working of all kinds of engineers from whatever branch of civil, mechanical or electrical engineering they may originate. Not that I would acquit the engineers from the fact that they have, at least partly, only themselves to blame; there is still a widespread opinion that an engineer who "merely" deals with the manufacturing of goods is inferior to the designer of the machinery producing these goods; thus he lets the "children of his inventive faculty" go into the practice and leaves them to the care of colleagues of lesser degree, just good enough for this minor job. I hope the reader will understand that this is not *my* opinion; but that I only try to explain the fact that few leading persons in the metallurgical industry are engineers compared with those trained in metallurgy, commerce or administration. It would be interesting to have this statement verified by actual statistics, as no real figures are at my disposal. Thus I can only speak about the impression I have obtained in the two decades during which I had an insight into these industries, and which is confirmed by many conversations with colleagues of similar experience.

Be that as it may, we have to recognise the fact stated in the initial remark of this article, and to ask how the deficiencies can be eliminated and improvements brought about in a department, so important for the efficiency of the whole works.

What does "Maintenance" mean?

But before this question of improvement is answered it may be commendable to define a little more in detail what is understood under the comprehensive expression, "maintenance," in these works. As this depends lastly on the individual circumstances the explanation may be given by a diagrammatic representation of an example (Fig. 27), taken from the well-known "Cost and Production Hand-book,"* which is reproduced unchanged, in spite of the fact that the denotations do not always coincide with those usual in English metallurgical works. It gives simultaneously an example of the organisation of such a department managed by a chief engineer and three assistants.

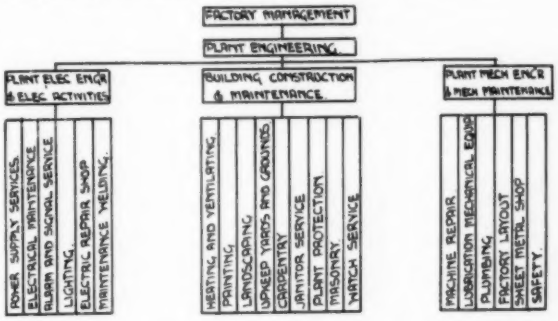


Fig. 27.—Example of the organisation of maintenance

Maintenance Orders

Returning, however, to the question of how to improve the working conditions in this department, the answer is comparatively simple in principle, though often it is not easy to accomplish the propositions in practice; this department has to be developed and managed according to the leading ideas, which to-day are self-evident in modern machine factories.

It should work according to clear orders, either given by the actual production departments, because some trouble or breakdown has occurred at a plant, apparatus or machine, or originating from a system of continuous supervision, which shows where such a case of emergency would probably arise in the course of the production. It is a test of the efficiency of this system of supervision that the former kind of orders disappear more and more and with them the surprising breakdowns and unpleasant stoppages which so often upset the planning of production and increase the difficulties of works and departmental managers.

This system of supervision must be built up on regular inspections repeated after periods, the length of which must be carefully adapted to the various kinds of parts of the plants; in fixing these periods one should be guided not only by figures given in literature, but also by former experience obtained in the very works in question, because the actual state of the plants plays an important role; it is therefore clear that the chief maintenance engineer should have a decisive influence on the establishment of this plant.

Limiting Repair Expenses

In this connection a problem may be touched which is sometimes considered excessively important in administrative circles: how to limit the expenses of repairs under the existing working conditions of the plants? It is then pointed out that this could best be done by limiting the power of the chief maintenance engineer to carry out major repairs without a special permit from his superior, the general manager or managing director. I do not agree

*Edited by L. P. Alford and published by the Ronald Press New York, 1934. Page 757.

to this instruction, the chief engineer, one of the leading persons of the undertaking, must be a man not only of sufficient experience, but also of confidence, who can be trusted not to allow any extravagance. This method of limiting his liberty of decision is dangerous, as it leads only too easily to the omission of desirable repairs or to the well-known method of veiling by dividing a major repair into a series of minor ones under the free expense limit, in cases where the maintenance engineer wants to avoid the trouble of discussing the matter with the higher authority. Besides, an abundant repair account is mostly economical in the long run. Perhaps it is not superfluous to add that these remarks do not refer to new investments, but that is outside of the scope of this article.

Spare Parts

The necessary supposition that the above-explained system of supervision, and the plan based upon it, can work efficiently is that a very carefully selected store of spare parts is always at hand and kept in order, not only so that each can be found easily, but in a state that it can be used immediately without special preparation or adjustment. In this connection the protection against corrosion may be mentioned.

The question, whether spare parts may be necessary, can be answered best by close co-operation with the supplier of the plant or machine, and especially with the production engineer, who is responsible for the correct working of the plant ; but as both are obviously inclined to put their demands as high as possible, the maintenance engineer should know from experience how far he has to give way to these demands for a super-investment in the store of spare parts, unemployed capital in itself, should be avoided.

Attention may further be drawn on this occasion to a mistake which can often be found in practice—i.e., to manufacture in their own machine shop spare parts which can be delivered cheaper, and generally of better quality, by the original supplier or another factory better equipped for the particular kind of work than their own shop, which is and must be only a repair shop rather than an independent factory of new machinery. For instance, I remember the turning of a piston rod of a big steam hammer, in spite of the fact that there was no lathe in the repair shop heavy enough to do this kind of work properly, and that a machine factory especially efficient in such work was only a few miles away ; but the maintenance engineer was too ambitious to admit that somebody else could do a better job than he, and the works had to suffer the loss.

Maintenance Programme

The orders to the maintenance department should be prepared, planned and progressed as usual production orders are prepared to-day for production departments of a modern factory. It is a mistake, mostly arising from the mental inertia of the maintenance engineer, to declare that these jobs are not suitable for a careful preparation in the drawing office as well as for estimation and observation in the planning department. As a matter of fact, this means, exactly as in the production department, nothing else than transferring something that is the duty of the leading maintenance engineers to their foremen with the result that the work is done worse and is more expensive ; at least that would be the result if such an engineer is the wrong man for his job, in which case one can certainly do nothing better than to replace him by a more efficient man. It is almost unnecessary to emphasise that these remarks about preparation and planning do not refer to a work of emergency arising from any breakdown, etc. ; but as already pointed out, these cases should happen only rarely.

In speaking of the planning of maintenance work, not only is the establishment of a programme of the work taken into consideration, but also of an approximate time table. This is often stated to be an impossible demand, as nobody could foresee how long a special repair job would take. It is perhaps given as an example that when overhauling a machine tool it may be unexpectedly found that a bearing has to be replaced, or any other part, the inspection of which was impossible before the machine has been taken to pieces. This is only half the truth ; it may be admitted that it *can* be the case, and when it happens an addition to the originally calculated time must be made, exactly as in the production department when something unforeseen by the calculator must be carried out ; but, again, it can be stated that these surprising cases of additional work will disappear, the more and the better the continuous supervision of the whole works, in regard to maintenance, is organised.

Piece-work Wages for Maintenance Jobs

On the other hand, it is sometimes concluded from this fact that a certain calculation of the working time of repairs is possible, that a piece-work system could and should be introduced, at least in so far as these jobs should be done in the machine shop, which forms ar important part of the maintenance department.

If exceptions are disregarded, as, for example, the manufacturing of standardised bolts or screws, which are used on various parts in the works and can therefore be produced in batches of sufficient numbers, the experience of the writer of these articles has shown that a system of piece-work wages cannot be recommended for maintenance jobs. The reason is not only the difficulty of determining in advance the exact time of the work—the estimation mentioned before is accurate enough for planning purposes, but not as a basis of piece-work,—but first of all that it is almost unnecessary to give any impetus to the men doing this kind of work. The men in question are, or at least should be, the elite of their profession—the best fitters, turners, electricians, etc., who can be found in the works,—for they have to carry out very responsible and, because of its variety, mostly very difficult work ; they must, further, be men of good and reliable character, and as they know that the work of their mates in the production departments depends on their own work, and that losses by stoppages will increase for them if they take too much time for the repair, they will certainly do their best. Considering these conditions of work, it should be preferred to pay these men on day work, but of course at a rate above the average, and adapted to their high professional and moral standard.

The Machine Shop

In the course of these considerations the machine shop has already been mentioned ; but being perhaps the most important part of the maintenance department and showing nearly always more or less strong deficiencies, it is necessary to discuss the usual working conditions in the machine shops of iron and steel works more in detail.

As far as situation and building is concerned, one has the impression that the former is very often casual, and that the latter is chosen because the building has been useless for any other purpose. And yet, how much money could be saved by using the necessary care in both cases. It is obvious that the machine shop, if fully centralised, should be as near as possible to the centre of the works in order to shorten transport as well as the movement of men, for whom this shop is merely the starting point when beginning a new job in one of the production departments, to the place where they can find their foreman for any information.

The building should satisfy the usual needs of a shop in a modern machine factory with sufficient space between the machines, light, heating, ventilation, etc., but how often is it, for example, located in some corner in the building of the rolling mills, not separated from these shops with their usual dust, which is so detrimental to any good machine tool. These buildings are also rarely constructed for supporting the necessary transmissions, and special auxiliary constructions must be erected, otherwise the better, but somewhat expensive, expedient of single drive for all machine tools is chosen.

And now the machine tools themselves. I well remember an excursion to an iron and steel works, where the managing director, grown up in these works from the position of an apprentice, and already beyond his golden jubilee, asked me to point out the weak points of his plant. I did not like to offend the man, who had shown friendly hospitality to his visitors, and reservedly begged for information of the age of the machine tools in his maintenance shop. The answer was that, unfortunately, he could not give correct dates, because the machines had been in operation years before he had been connected with the works. One may say that that was an exception, but I am not so sure. The skilled observer has only too often the impression that these machine shops are a collection of machine tools which could not be used for other purposes, but are considered suitable for this shop, because only "repair jobs will be carried out with them"; and the question of the age of the one or other is not rarely answered by the remark "unknown, for we have bought it second-hand."

There is no question that this point of view is absolutely wrong; repair work needs often an accuracy which is not only unusual in the production departments of iron and steel works, but even surpasses the accuracy necessary in general machine factories. Further, in the maintenance department, the economical point of view should not be neglected; it is, however, very seldom possible to work with an old second-hand machine tool as economically as with a new modern one; it should be sufficient to compare illustrated catalogues of any well-known manufacturer of machine tools of, say, 10 years ago and of to-day. The form has changed completely; bigger forces can be exercised, greater speeds and feeds taken, modern tools of high-speed steel, or even hard metal, are used, etc., and the work can be carried out by new machines with the small tolerances characteristic of good repair work, tolerances which are either impossible on older machines or only possible at a much higher cost.

Tools

The maintenance of tools is another matter which sometimes is not given the necessary attention. Mention may be made, for instance, to the importance of a central grinding shop for all cutting tools, milling cutters, drills, saws, chisels, etc. It is astonishing how few people in steel works, who know the importance of the quality of tool steel, recognise the economical influence of the correct form of the cutting edge, and leave the grinding of tools more or less to the discretion of the workman. The careful administration of all tools by one or several tool store-rooms, the control of the use of tools by means of adequate book-keeping, and a suitable box or cupboard for each man who has to handle and to keep tools, should be self-evident; but how often are these things neglected and the necessary equipment in a deplorable state. The same applies to almost an equal extent to gauges and other measuring instruments, in spite of the need for accuracy. It would be easy to write a special article on these questions, but here these few hints may be enough.

Maintenance Work Outside the Machine Shop

Other problems arise for the numerous gangs of men and individual workers, whose duty it is to do maintenance work scattered all over the works, which frequently cover an area of many acres. Here especially it is the question of supervision which makes difficulties, and often gives the so-called "organiser" an opportunity for uneconomical over-organisation. Certainly, some programme should exist for these men, and occasional control must be carried out by the foreman or maintenance engineer, but the nature of the job and the long distances to the work make it inevitable that to press for accurate time-tables is silly. One must depend on the good will of the men to do their best in an adequate time, and therefore a careful selection of these men is of special importance. Again, the problem of tools should be a matter of attention; it is not a rare occurrence that, after arrival to carry out necessary repairs, it is found that the tool necessary is forgotten or in a bad state. Easily transportable boxes with tools, carefully selected for the usual work of the gang or the man, and safely fixed in corresponding shaped positions in the box, should be developed and maintained in good order by periodical inspection and repair in the tool repair shop, which is, nearly always, best closely connected with the machine shop.

The Clerical System

It is clear that a clerical system is necessary for recording the material used for maintenance work, and the time spent for each order carried out. As the men are working throughout for an hourly or daily rate, it is easy to calculate with sufficient accuracy the costs of the individual order and to compare them with the estimate made beforehand. If the demand to use a clerical system as simple as possible is appropriate in any case, it is of special importance for maintenance work, and it should be adapted to the particular circumstances under which the men have to work, especially those outside the machine and repair shops who are on the plants of the works. As the orders are mostly handed to them on loose sheets written in the office, where a copy is kept for reference purposes, the temptation is great to ask for returning these orders with the necessary dates of material and wages, as then any copying and duplicating of work, with all its well-known disadvantages, is avoided. This cannot be denied, but the experience in practice has brought to the writer of these articles the conviction that it is mostly better in cases like those which are here discussed to adhere to the old-fashioned method of note-books or diaries, where the workman or the charge-hand of the gang enters what has been done and how much time was taken. Two books are in use, one for the first, third, fifth, etc., week, the other for the second, fourth, sixth, etc., so that the office can extract always during the next week what has occurred during the previous one without disturbing the continuous book-keeping by the men. A pocket may be connected with the book for keeping as long as necessary the order sheets the owner of the book has received.

If this method is adopted, the handling of loose sheets by the men is reduced to a minimum, and this is an improvement, especially having regard to the conditions under which the men have to work; it gives a continuous report of work made by the men which they will always recognise as correct; a report, moreover, from which conclusions can be drawn that are as near to the truth as possible, in spite of the comparatively small supervision which this kind of job allows. This report contains a survey of a man's day work without any compilation from several loose sheets, and so gives the experienced foreman a direct help in control which he will greatly appreciate. It may perhaps be necessary to repeat that these remarks apply to the work of men who are characterised above as of a high order, trustworthy in so far as they will do their best to give really true reports.

These remarks on maintenance work must be sufficient, although the reader may have the impression that only a very superficial survey has been given; but if the conviction is obtained that here is really a province which needs greater care and attention than is usually given, all is done that can be expected from such a short article.

Obituary

It is with deep regret that we announce the death of Mr. John H. Webster, chairman and joint managing director of Messrs. King, Taudevin and Gregson, Ltd., who passed away on October 22, 1939.

We deeply regret to record the death, on Thursday, November 2, of Mr. Wilfred R. Hill, who for over 20 years had acted as representative of the Carborundum Co., Ltd., Trafford Park, Manchester, on the North-East Coast.

The Constitution of Dilute Alloys of Lead with Sulphur, Selenium and Tellurium*

By J. Neill Greenwood, D.Sc., and H. W. Worner, M.Sc.

A STUDY of the solid solubility at 300° C. of sulphur, selenium and tellurium in lead has been made by micro-examination and determinations of electrical resistance. It forms part of a comprehensive study of lead, and its dilute alloys, which is being undertaken in the Rosenbain Memorial Laboratory of the University of Melbourne. It is known that certain elements which exert a profound influence in modifying the properties of lead are only slightly soluble, and so it is probable that interesting information of a fundamental type will be obtained when the study is extended to the determination of the detailed influence of slight solubility on such properties as creep-resistance, work-hardening capacity, spontaneous annealing, etc.

For this study two qualities of pure lead were used to make the alloys. These were a very pure sample of commercial lead (SA) containing 0·0023% of impurities, and electrolytic lead prepared from this and containing 0·0005% impurities. The elements, sulphur, selenium and tellurium, were the purest commercial products, and as the alloys used all contained less than 0·05% of alloying element, it was not considered necessary to purify them.

In each case a mother alloy was made by direct combination of the given element with "SA" lead at temperatures between 800° C. and 850° C. These alloys were chill-cast, sampled and analysed. The compositions of the mother alloys were:

Sulphur-lead	0·84% sulphur.
Selenium-lead	2·43% selenium.
Tellurium-lead	2·15% tillurium.

Some of the very dilute alloys were made by using a 0·5% or 0·2% alloy as a secondary mother alloy. These latter were prepared by vacuum melting, and were not analysed. Preliminary experiments showed that the region to be explored in each case was below 0·05% of the added elements; the final alloys were, therefore, prepared in a furnace which could be either evacuated or filled with a hydrogen atmosphere at will.

From the micro-examination of specimens, including the actual appearance of PbS and the absence of dendritic coring, and of finer particles of the second phase, it was concluded that the solid solubility of sulphur in lead is less than 0·0001% by weight, or 0·0006 atomic %. Since, with this percentage, the sulphur appeared as a primary PbS phase, it was concluded that this same limit can also be placed to the solubility of sulphur in molten lead at the melting point.

With regard to the alloys of selenium with lead, it is concluded, from micro-examination of specimens, that there is a eutectic at 0·005%—0·013 atomic %—and a solid solubility limit at 300° C. of 0·0015%—0·004 atomic %. The eutectec melts at a temperature 0·2° C. below the melting point of lead. Selenium in solid solution lowers the specific resistance of lead (at 17° C.) from 20·65 to 20·61 micro-ohms/cm.[3]

From similar examinations of specimens of the alloys of tellurium with lead, it is concluded that there is a eutectic containing 0·025%—0·04 atomic %—tellurium. This has a melting point 0·7° C. below that of pure lead. The limit of solid solubility at 300° C., as determined by micro-examination, is 0·004%—0·0065 atomic %—tellurium. This is confirmed by electrical resistance determinations. The specific resistance at 17° C. of pure lead is increased from 20·65 to 20·71 micro-ohms/cm.[3] by 0·004% of tellurium in solid solution.

In the conclusion given in this report the author states that sulphur, selenium and tellurium are members of group VI B in the periodic system. The first of these crystallises in the orthorhombic system, and the other two in the hexagonal system, whilst lead itself is cubic. These conditions alone would not appear very conducive to solid solubility. When it is an addition, it is found that each of the three elements forms with lead a stable compound of a normal valency type the chances of forming solid solutions is still further limited. An interesting point is the low solubility of the three elements in lead at the melting point of the latter, as shown by the extreme dilution of the eutectic compositions.

Table I gives a summary of the values found as a result of this investigation.

TABLE I.

Element.	Solid Solubility at 300° C.	Eutectic Concentration.
Sulphur ...	Less than 0·0006 atomic %	Less than 0·0006 atomic %
Selenium ..	0·004 atomic %	0·013 atomic %
Tellurium .	0·0065 atomic %	0·04 atomic %

It will be noted that both the solubility at 300° C. and the eutectic concentration increase with the atomic number of the added element. Whilst the actual depression of the freezing point of lead by the addition of these elements is small, the atomic depression is very high. In the case of selenium, the depression is at the rate of 15° C. per atomic %, whilst for tellurium the corresponding value is approximately 17° C.

*J. Neill Greenwood and H. W. Worner, *J. Inst. Metals*. Vol. 6, Part 10. Page 513 (October, 1939.)

Forthcoming Meetings

ALTHOUGH there will inevitably be some reduction in the usual programmes, it is interesting to note that several Institutes and Societies have made arrangements for the winter session. Sheffield Metallurgical Association have already held two meetings to hear lectures by Dr. W. H. Hatfield and Prof. J. H. Andrew, respectively, and a third meeting is being held on November 21, when Dr. T. Swinden will lecture on "The Work of the Oxygen Panel."

The Electro-depositors' Technical Society hopes to hold a number of meetings in both London and Birmingham. The first was held at the James Watt Memorial Institute, Birmingham, November 16, when the chairman, Dr. H. Saenger, delivered an address on "Economics of the Electro-plating Trade." The first meeting in London takes place on November 20, at Northampton Polytechnic, when a paper on "Structure and Properties of Nickel Deposits" will be presented by A. W. Hothersall, M.Sc., and G. E. Gardam, Ph.D., A.R.C.S.

The North-East Coast Institution of Engineers and Shipbuilders has issued a complete programme for the session, and on November 24 Dr. J. Lockwood Taylor will present a paper on "Aeronautics and Ship Design." On December 15 Mr. L. Troost will present a paper on "Open Water Test Series with Modern Propeller Forms." Part II—"Three-blade Propellers." The meetings will be held at the Mining Institute, Neville Hall, Newcastle-on-Tyne.

The Deep Drawing of Aluminium

By A. G. C. Gwyer, B.Sc., Ph.D., and
P. C. Varley, M.A., A.Inst.P.

Its ability to withstand repeated drawing operations without the necessity for any intermediate anneals, and also its lightness, non-toxicity, cleanliness, and attractive appearance, are increasing the use of aluminium and its alloys for deep-drawn articles. Favourable drawing conditions and suitable tests for deep-drawing qualities are discussed. Experiments are described which show that the thinner the metal the less is the possible reduction in deep drawing. This paper was prepared for presentation at the Second Aluminium Congress at Zürich, which could not be held on September 12–14 as arranged, owing to the outbreak of war.

OF the many deformation processes for the shaping of metals, that most suitable for the mass production of thin walled, hollow vessels is deep-drawing. In this process a sheet of metal, of appropriate shape is forced through a die or into a cavity of the required shape in such a manner that the desired deformation is accomplished without excessive wrinkling. A great variety of articles can be made by this process, ranging in size from eyelets for boots and shoes to parts of motor-car bodies, and in depth from shallow trays to bicycle pumps. All such processes are characterised by the fact that the starting-point is a sheet-metal blank of suitable size and shape and having roughly the same thickness as is required in the finished product.

Most metals which are available in sheet form may be formed by deep drawing, and whilst mild steel, brass and aluminium are the metals most commonly used in this way, copper, zinc, nickel-silver, cupro-nickel, and aluminium-bronze are also used, as well as many of the alloy steels. All these materials will, in their annealed condition, stand very much the same amount of deformation in the first draw—i.e., between 50% and 55% reduction in diameter from the blank to the drawn shell, and in this respect aluminium does not appear to be outstanding; it is, for example, inferior to brass, but where it does show to advantage is in its ability to withstand repeated drawing operations without the necessity for any intermediate anneals. For this reason, and also because of its inherent advantages, such as lightness, non-toxicity, cleanliness, and attractive appearance, the use of aluminium and its alloys for deep-drawn articles is rapidly expanding, and much research has been done both from the point of view of working out the most favourable drawing conditions and of developing suitable tests for deep-drawing quality.

The influence of variations in die clearance, blank-holder pressure, and punch and die radii have been studied extensively by Hermann and Sachs,[1] and later workers, such as Goderitz[2] and Helling[3] have confirmed their conclusions. It would appear from this work that for normal working the die clearance should exceed the metal thickness by an amount between 10% and 25%. Below this there is a marked increase in the load on the punch, due to the ironing of the wall, which normally tends to thicken up considerably when drawn into the die, whilst when the die clearance is excessive the load on the punch is also increased due to the formation of wrinkles,[2] and since in such a case the load is borne exclusively by the metal, failure may result, whereas with lower clearances some of the load is taken by friction against the punch.

The blank-holder pressure is also important, as if it is too high the metal is held too tightly and breaks, while too small a value allows the blank to pucker, which, apart from spoiling the appearance of the drawn shell, adds to the resistance to drawing and may easily lead to fracture. In any given operation the most suitable pressure is best found by trial and is the minimum required to prevent puckering.

Sachs[1] has also shown that the drawing capacity increases both with the radius of curvature of the die and with that of the punch, though he does state that if the radius on the punch exceeds 0·3 of its diameter premature failure of the shell may take place. We have found that this is true for the work-hardened tempers of aluminium, but that with the soft metal a hemispherical punch appears to draw more deeply than a flat-bottomed one.

Many workers have also studied the question of a simple test to determine the deep-drawing quality of a metal sample. Originally, the Erichsen No. 1 test was extensively used for this purpose, but recent work has rather discredited it. Gough and Hankins[4] have examined the question of cupping tests generally and have come to the conclusion that, as a measure of ductility, no form of cupping test possesses marked advantages over the others or over the elongation value obtained in the tensile test.

Sachs[5] has devised a wedge-drawing test in which a wedge-shaped test-piece is drawn through guides in such a way as to simulate the drawing process without the complication of bending stresses over the drawing edge. This test has given satisfactory results in the hands of some workers, but has not yet met with general acceptance. Siebel and Pomp[6] have put forward still another test, in which a previously perforated sheet is punched with a cylindrical punch. In this case the extent to which the original hole is widened before splitting is taken as a measure of the ductility.

Because of the difficulty of devising any simple test which may be readily and rapidly carried out, an increasing number of investigators have employed small scale deep-drawing tools to determine the deep-drawing properties of various metals. G. R. Fischer,[7] for example, used as a criterion of drawing quality the largest size of circle which would draw through a standard die with 50% failures. Both Goderitz[2] and Helling[3] have used the Erichsen machine with special deep-drawing tools, which convert it into a miniature draw press, while the present authors[8] have carried out similar tests with small-scale tools on a hand-operated draw press, and have also confirmed their conclusions by experiments on a full commercial scale.

Goderitz's work was concerned more with establishing the form of the curves connecting punch and blank-holder pressures with the depth of draw, but he established that the following reductions were possible in the first draw :—

Copper	Between 40% and 50%
Zinc	Between 40% and 50%
Soft Iron	More than 52·9%
Soft Brass	More than 52·9%
Silver	More than 52·9%
Aluminium	Between 50% and 52·9%

1 W. Hermann and G. Sachs. *Metallw.* 13 (1934), pp. 687-92, 705-10.
2 H. F. Goderitz. *Z. Metallkde.* 26 (1934), pp. 49-55.
3 W. Helling. *Metallw.* 15 (1936), pp. 388-394, 409-412.
4 H. J. Gough and G. A. Hankins. *J. Roy. Aeronaut Soc.* 39 (1935), pp. 1047-1076.
5 G. Sachs. *Mitt. D. Materialprüfungsamt Sonderh.* 16 (1931), pp. 11-38.
6 E. Siebel and A. Pomp. *Mitt. K.W.I. Eisenforsch.* 11 (1929), pp. 287-91.
7 G. R. Fischer. *A.E.G. Mitt.* (1927), pp. 419-20. (1929), pp. 483-86.

The present authors[8] found for aluminium of commercial purity that soft-temper aluminium would withstand 50·5% and the intermediate tempers 49·2% in the first draw, while reductions of as much as 33% for soft and 40% for the intermediate tempers were possible on redrawing.

Helling's results are rather different, in that they show better properties for the ¼ and ½ hard tempers of aluminium than for the annealed metal. His average results for aluminium from five different sources were :—

Soft	50·3%
¼ Hard	50·8%
½ Hard	50·8%
¾ Hard	49·8%
1/1 Hard	50·3%

Thus, according to Helling's experiments the ¼ and ½-hard tempers both draw deeper than the soft temper. On the other hand, his figures for soft are inferior to our earlier published figures, and considerably lower than those obtained in the further experiments to be described below. This inferiority is in all probability due to the very coarse grain of his samples (30–70 grains/sq. mm.).

The following sizes of circles, all 0·032 in. thick, were used, the corresponding reduction being indicated :—

Circle diameter in inches	2	..	2¼	..	2½	..	2¾	..	2 7/8
Per cent. reduction	38·0	..	41·6	..	44·9	..	47·8	..	49·2
Circle diameter in inches	2⅛	..	2 5/16	..	2⅜	..	2 11/16		
Per cent. reduction	50·5	..	51·6	..	52·8	..	53·9		

Our procedure in these tests is as follows : After assembling the tools and adjusting the spring pressure on the blank-holder, so that wrinkling is just prevented, we draw 20–30 circles of the smallest size. When these have been drawn, the next size is put through, and so on, each circle being lubricated before drawing with a mixture of tallow and machine oil. Working in this manner—i.e., increasing the circle diameter in a progressive manner, so that the tools are warmed up, we find it possible to draw a larger diameter of circle than is possible with cold tools. The same die is used for all tempers, but we have found by experience that while soft-temper draws satisfactorily with a chamfered punch such as is generally used when a redrawing operation is required, the intermediate tempers

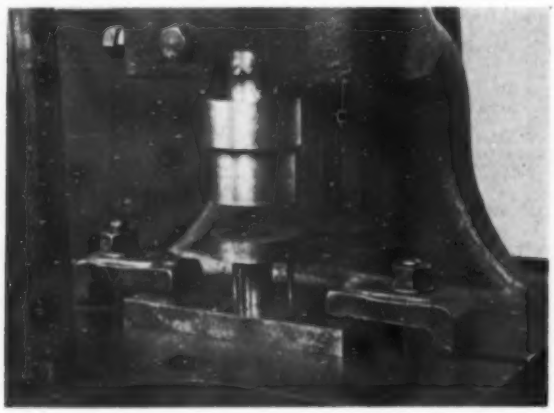


Fig. 1.—First draw tools in position.

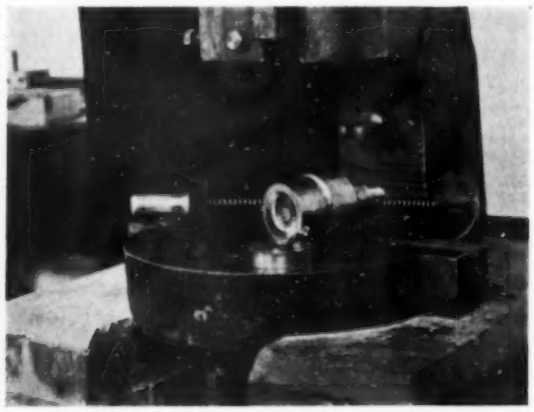


Fig. 2.—First draw tools, showing details.

Recently we have been continuing our experiments on the deep-drawing quality of aluminium with redesigned tools, Figs. 1 and 2. These tools differ from the earlier ones[8] only in the method of fixing the top member or die to the ram of the press. Actually, the original die wore out and in replacing it we took the opportunity to improve the method of fixing. The new die appears to have been more satisfactory than the old one, although its diameter and the radius on the drawing edge were exactly the same as far as could be determined by the most careful measurements.

However, using this new die not only were we able to draw more deeply than before, but we now find that, contrary to the opinion expressed in our earlier paper, it is possible to detect differences in drawing quality by the behaviour of the metal in the first draw alone. We must emphasise, however, that the indications as to the relative drawing qualities of two grades of metal, as given by the first and second operations, are often quite different. This is particularly the case when comparing soft-temper material with ¼ or ½-hard, but it may also occur when both samples are of the same temper. Such differences are not altogether surprising, since the mode of deformation in the two operations is so different. The observation is of considerable practical importance in that it shows quite clearly that no single test can be expected to give a clear indication of the deep-drawing capabilities of a metal sample.

The actual dimensions of the tools used were :—

	In.
Punch diameter	1·240
Die diameter	1·314
Die clearance	0·037
Radii on punch and die	0·25

behave better if a flat-bottomed punch is used. Operating the test in this way—i.e., with a chamfered punch for soft and a flat one for the other tempers—we have obtained the following figures for the maximum permissible reductions, with no failures, in the first draw :—

Soft temper	51·6%
¼ Hard	50·5%
½ Hard	50·5%
¾ Hard	49·2%
1/1 Hard	49·2%

Comparing these figures with those obtained as a result of similar experiments by Helling, it will be seen that our results for soft temper are considerably higher, whilst we agree fairly well for the intermediate tempers. It must be remembered that the circle sizes cannot be varied continuously, and that, for example, our figure of 50·5% for ¼-hard means that this temper will stand this reduction without failure, but will not stand the next larger one—namely, 51·6%. The difference in the figures in soft temper must be due to variations in the conditions of experiment, probably the shape of the punch and the coarse grain of Helling's metal, and serves to show the difficulty of obtaining agreement between different workers when so many factors may have an influence on the reduction obtainable.

Our redrawing tools are very simple (Fig. 3), as with the thickness of metal used (0·032 in.) no blank-holder was necessary. The reductions obtained depended on the reduction given in the first draw. In this test we have several different sets of tools, giving reductions from 30% to 44%, and we record the largest size of cup which will stand these various reductions without failure.

8 A. G. C. Gwyer and P. C. Varley. *J. Inst. Met.* 58 (1936), pp. 83-96.

The diameters of the various punches and the exact reductions were :—

Punch diameter in inches ...	0·830 ..	0·792 ..	0·740 ..	0·690
Per cent. reduction	33·1 ..	36·2 ..	40·3 ..	44·3

The die clearance was in each case 0·037 in. as in the first draw.

In the following table we have entered, for each temper, the maximum possible second draw reduction for each of the first draw reductions given :—

Reduction in 1st draw ...	% 38·0	% 41·6	% 44·9	% 47·8	% 49·2	% 50·5	% 51·6
Soft	% 33	% 33	% 30	% —	% —	% —	% —
½ Hard	36	36	33	33	33	33	—
¾ Hard	36	36	36	33	33	33	—
¾ Hard	40	40	36	36	36	—	—
1/1 Hard	40	40	40	40	36	—	—

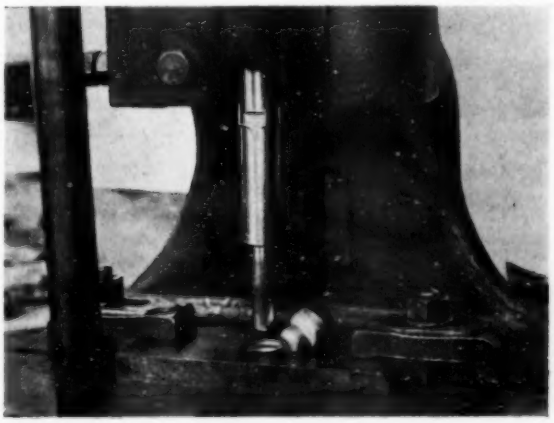


Fig. 3.—Second draw tools for 0.032 in. metal.

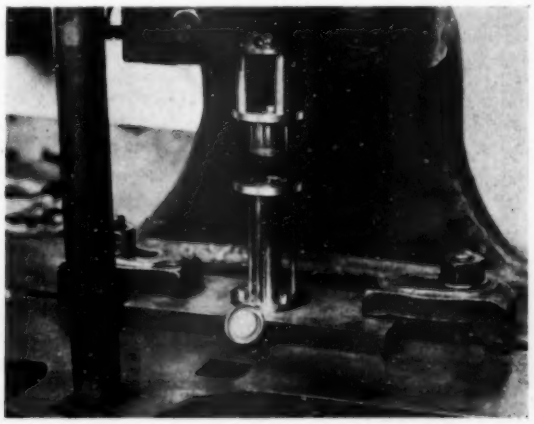


Fig. 4.—Second draw tools for 0.008 in. metal.

It will be seen from these figures that so far as redrawing is concerned the work-hardened tempers are considerably better than the annealed metal.

The above tests have given us a fair idea as to the behaviour to be expected from commercial aluminium, but they differ from commercial practice in that the ratio of blank thickness to blank diameter is much higher than normal, being 0·0128 as against a normal value of about 0·003. For this reason we have carried out further tests in order to determine what influence on our results a reduction in this ratio would have.

In the first place, we reduced the thickness of the metal used for our laboratory tests to 0·008 in., which with a circle about 2½ in. diameter gives about the same ratio as a 10-in. circle at 0·032 in.—i.e., 0·003. For the first operation the tests were carried out in a precisely similar manner to the earlier tests described above, but it was found that owing to the extreme thinness of the metal there was a pronounced sensitivity to variations in conditions of drawing, so that not only was the experimental error very greatly increased, but the maximum permissible reduction was decreased. Using various samples of soft temper metal, the mean reduction possible was 48·6%.

The tools used in the first draw had the following dimensions :—

	In.
Punch diameter	1·295
Die diameter	1·322
Radii on punch and die	1/16

The second draw tools were as follows :—

Punch diameter in inches ..	0·908 ..	0·889 ..	0·879 ..	0·868
Die diameter in inches	0·930 ..	0·911 ..	0·902 ..	0·889
Per cent. reduction	30 ..	31·5 ..	32·25 ..	33

The radii on the punches and dies were 1/16 in. throughout.

In the second draw a blank-holder had to be used, and for this reason the tools differed markedly from the ones used for the thicker metal. They are shown in operation in Fig. 4, from which it will be seen that the shell produced by the first draw is actually turned inside out. No other means were possible for fitting double-acting reduction tools to a single-acting press.

Here, again, the experimental error was high and the shells showed a pronounced tendency to tear, but it would appear that the majority of the shells would withstand 30% reduction in the redrawing operation, but very few would stand 31·5%.

A parallel investigation was carried out, using 0·022 in. metal and circles up to 13½ in. diameter, giving ratio of 0·0017. These tests were carried out on a commercial double-acting press with a flat-bottomed punch and die producing 6½ in. diameter straight-sided shells. No redrawing tests were carried out as no suitable tools were available. The utmost care was taken that in all cases the blank-holder pressure was adjusted to give the best results with the particular size and temper of circle being drawn. The results obtained were :—

Soft temper (straight rolled)	49·2%
½ Hard	51·1%
1/1 Hard	48·6%

These results are interesting in that although the ratio of blank thickness to blank diameter is lower than with the 0·008 in. metal, the reductions obtainable are higher. In fact, it would appear that a better correlation exists between maximum reduction and metal thickness than between reduction and ratio thickness to diameter.

They are also interesting in that they agree with Helling's results in showing a greater permissible reduction with ½-hard metal than with either soft or hard.

At the same time, we also carried out tests with a hemispherical punch and a 5-in. diameter die, the metal being in two thicknesses—namely, 0·036 in. and 0·022 in. It was found that the following reductions were possible :—

Soft temper	0·022 in. 52·1%
"	0·036 in. more than 52·7%
½ Hard	0·022 in. and 0·036 in. less than 47%
1/1 Hard	0·022 in. and 0·036 in. less than 47%

Thus it would seem that for soft temper a hemispherical punch permits of greater reductions than a flat-ended one, but that for the work-hardened tempers the reverse is the case, and to this extent Sach's statement that the radius on the punch must not exceed 0·3 of the diameter must be qualified.

Two further phenomena that we have investigated should be mentioned. In the first place, we stated above that by allowing the tools to warm up on small sizes we were able to draw a larger maximum size of circle than otherwise. This observation which was first made on the laboratory press was subsequently confirmed during our commercial scale experiments, and we have since carried out some experiments to determine whether this warming-up process

could be accelerated. We have found that by warming either the metal or the tools to about 100° C. the warming-up process can be dispensed with and the maximum reduction given immediately.

The other phenomenon which we wish to mention is the formation of ears (Zipfeln) on the drawn shells. Annealed aluminium of normal commercial purity gives only very small ears situated at 45° to the direction of rolling; ¼-hard and ½-hard tempers give rather larger ears in the same relative positions. In no case, however, should the magnitude of these ears be objectionable except perhaps where a number of draws is given such that the shell is very deep in comparison with its diameter. Soft aluminium of very high purity, sometimes gives ears in the direction of rolling and at right-angles to it.

So far we have not considered the implications of these tests from the point of view of the practical employment of the metal for the manufacture of articles by deep drawing. In the first place, it would appear that, for the manufacture of a straight-sided, flat-bottomed cylindrical vessel in one draw, soft, ¼-hard, and ½-hard tempers are equally suitable in that they will all withstand a little more than 50% reduction. It must, however, be remembered that ½-hard material will give a much stiffer product and that, if redrawing is contemplated, it will be very much more suitable, as it will stand heavier reductions and will not tend to become brittle due to overworking. So far as we can see the only type of work for which the use of soft temper is advantageous is where the shape to be produced is such that part of the deformation is produced by stretching the metal, as is the case in the production of dome-shaped articles. Here the much higher elongation of the annealed metal gives it a considerable advantage, but even here by careful design of tools it is often possible to take advantage of the greater strength and stiffness of ¼-hard temper.

With regard to the design of tools, it is important that these should be made from good quality steel and should have a high standard of finish if the best results are to be obtained. The radii on the punch and on the drawing edge of the die should be between 5 and 10 times the metal thickness unless the shape required demands a larger value. For normal work, the clearance between the die and the punch should be about 10% greater than the metal thickness. With smaller clearances than this ironing takes place and the load on the punch is increased so that the maximum permissible reduction is smaller. It may, however, be necessary for special purposes to reduce the wall thickness in this manner, in which case no attempt should be made to give a large reduction at the same time. On the other hand, if the clearance is much larger than the metal thickness, wrinkles may make their appearance, and the maximum reduction may be reduced, owing largely to the absence of frictional support from the punch. Normally, part of the drawing load is carried by the metal, and part is transferred to the punch by friction; when the clearance is large this latter effect cannot take place. Another disadvantage resulting from a large clearance is that the wall thickness increases towards the top, and this may lead to trouble in redrawing.

Normally, the face of the die and that of the blank-holder are flat and smooth, but it is sometimes of advantage when drawing domed shapes, such as reflectors, to introduce a bead. The function of this is to prevent the formation of the wrinkles, which are so difficult to avoid when drawing such shapes, particularly in ¼-hard metal.

In drawing aluminium adequate lubrication is of the utmost importance, and although little or no work has been published it would appear that lubricants containing animal fat are advantageous. Such lubricants are lard oil, and a mixture of tallow with a light mineral oil. Only a thin film of lubricant is required, but this should be applied uniformly to both sides of the metal.

In conclusion, we would say that aluminium appears to be a most suitable metal for deep-drawing, but that in order to obtain the best possible results it is essential to understand its properties and behaviour and to take the fullest possible advantage of them by choosing the most suitable temper and selecting tools appropriate to the job in hand and the temper and gauge of the metal being used. Much experimental work has been done on these points, but much more still remains to be done before our knowledge is sufficient entirely to eliminate guess-work.

The authors wish to express their thanks to the British Aluminium Co., Ltd., for permission to publish this work, and also to their colleague, Mr. J. H. G. Thomson, B.Sc., for his valuable assistance.

Licensing of Machinery Imports

THE Board of Trade issued, on October 23, an Order (Import Prohibition (No. 4) Order, 1939) prohibiting the import, except under licence, of machinery and plant. The Order came into force on October 25, but goods of the kinds affected which were dispatched to the United Kingdom before that date will not be subject to the Order.

In cases where an import licence has been granted, the Treasury wish it to be known that they are prepared to consider, under Section 10 of the Finance Act, 1932, applications for duty-free licences in respect of consignments of machinery falling within approved classes. A list of these classes is contained in Notice T.N.1, which, together with the necessary application forms, can be obtained from the Import Licensing Department (Machinery Licences Division) of the Board of Trade, 25, Southampton Buildings, London, W.C. 2, or in the case of machine tools from the Controller of Machine Tools, Portland House, 14, Tothill Street, London, S.W. 1.

The following "Notice to Importers" has been issued by the Import Licensing Department (Machinery Licences Division):—

Machinery, Plant, Appliances or Parts

The importation of certain machinery, plant, appliances or parts is prohibited under the Import Prohibition (No. 4) Order, 1939, except under licence issued by the Import Licensing Department of the Board of Trade. The following explanations are given for the convenience of importers:—

1. Machinery, plant, appliances or parts on the list which are shown to the satisfaction of the proper Officer of Customs and Excise at the time of importation to have been dispatched to the United Kingdom before October 25, 1939 (the date on which the Order came into force) are not subject to the Order. In respect of any other machinery, etc., importers are warned that they should not arrange to ship until they have obtained a licence.

2. When making the Customs Entry for any listed machinery, etc., the importer must furnish to the Customs one extra copy of the Entry.

3. Persons who have imported any of the machinery, etc., in respect of which licences may be issued and who wish to continue to do so, should apply at once to the Import Licensing Department, Machinery Licences Department, 25, Southampton Buildings, Chancery Lane, London, W.C. 2, for application forms for licences.

4. The Department will have regard particularly to the following considerations in coming to a decision whether a licence may be issued for machinery, etc., specified in any application:—

(1) The possibility of obtaining from manufacturers in the United Kingdom other machinery, etc., as the full equivalent or as an efficient substitute.

(2) The general desirability of deferring the importation of machinery, etc., which is not required for work of national importance.

5. *Machine Tools.*—The control of Machine Tools is regulated by the Control of Machine Tools (No. 1) Order, 1939, and import licences will be issued only to importers approved by the Controller of Machine Tools. Application should be made in the first instance to the Controller of Machine Tools, Portland House, 14, Tothill Street, S.W. 1, for permission to be included in the list of importers.

A Recent Heat-Treatment Furnace Installation

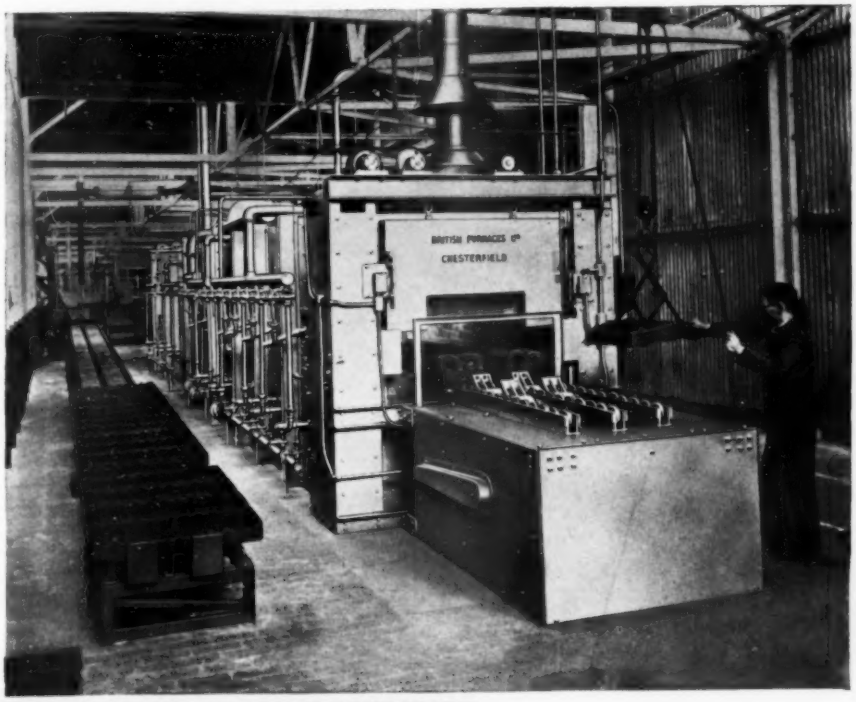
By P. Hopkinson.

Furnaces of the continuous type are discussed; such furnaces provide a regular input and output of material and control of the factors affecting time and rate of heating which result in uniformity of products.

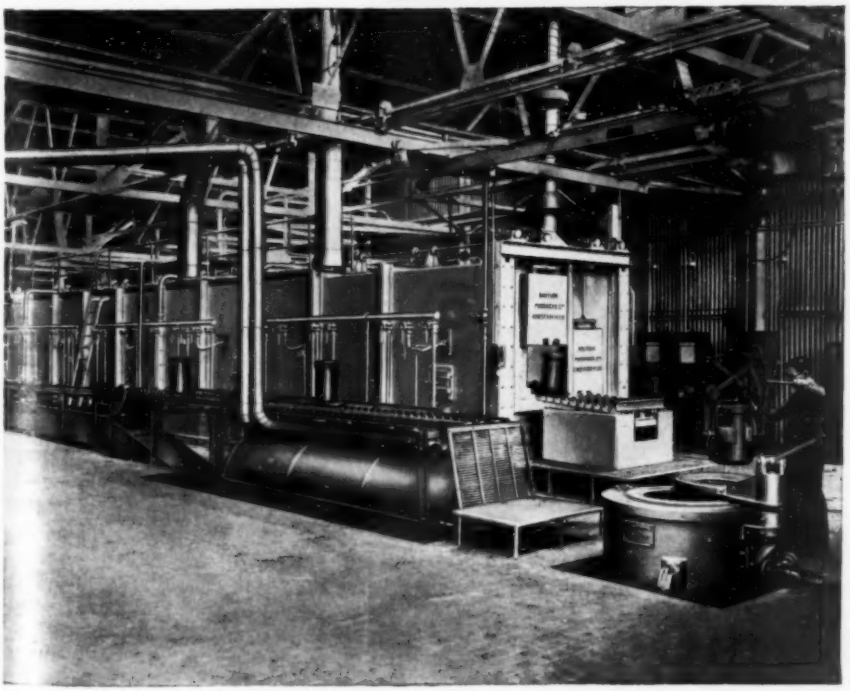
AN excellent example of the trend of development in the design and construction of modern heat-treatment furnaces is an installation at the Luton works of Messrs. Vauxhall Motors, Ltd., comprising normalising, carburising, reheating and drawing furnaces, all of the continuous type and town's gas-fired.

Normalising Furnace

The furnace is designed to handle approximately 1,000 lb. of forgings per hour, and the work is loaded on heat-resisting alloy trays. The gross load passing through the furnace is approximately 1,390 lb. per hour, and the temperature in the hot zone can, if necessary, be as high as 985° C. The trays carrying the work are pushed through the furnace over three rows of heat-resisting alloy rollers set in beams of the same material.



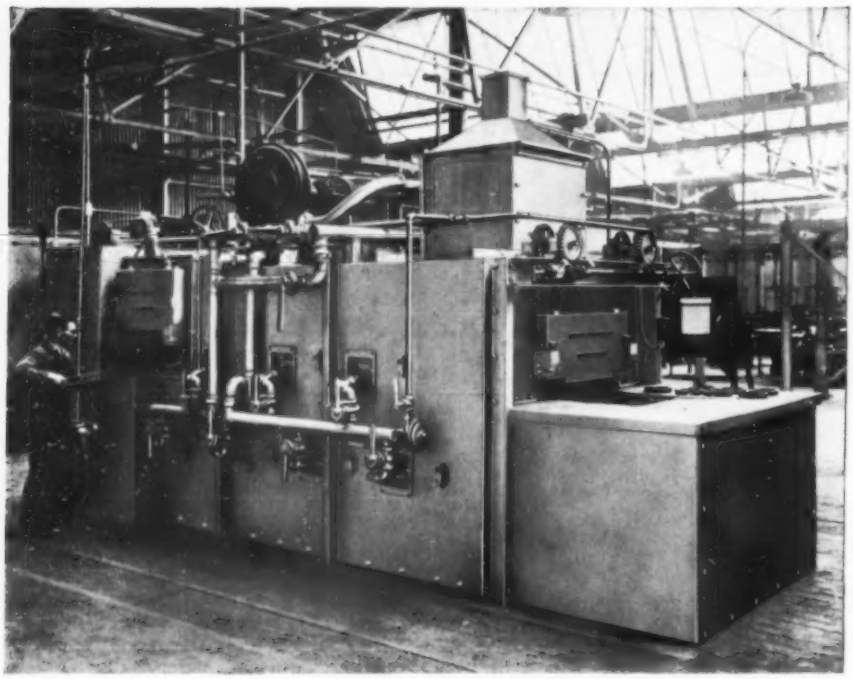
Discharge end of carburising furnace.



Charge end of normalising furnace

The electrically-driven rocker-arm pusher is synchronised with both the charge and discharge doors, and all operations are completely automatic throughout the cycles of charge and discharge. As the pusher need only operate once every 16½ mins., this is not kept running continuous, but is started at correct intervals by means of a special time clock.

The furnace has several zones covering heating, soaking and various cooling rates, and the temperature is automatically controlled by Leeds and Northrup instruments throughout. The internal dimensions are 3 ft. 9 in. wide × 44 ft. long, and the hot zones have 9 in. of high-quality insulation throughout in order to minimise heat losses as much as possible. This construction, together with the use of automatic proportioning burner equipment,



Continuous type reheating furnace.

giving maximum combustion efficiency, ensures a low fuel consumption. When operating on a nett capacity of 1,000 lb. per hour, corresponding to a gross output of 1,390 lb. per hour, and a temperature of 980° C. in the soaking zone, the gas consumption is 2,700 cub. ft. per hour.

Carburising Furnace

This furnace is of the double row, single-flow type, with all the charge passing through the furnace in the same direction, and is designed to deal with a gross charge of 1,200 lb. per hour, with a case depth between 0·045 in. and 0·055 in. at a working temperature of 925° C. The trays carrying the boxes are pushed through the furnace over four rows of heat-resisting alloy rollers in a similar way to what is done in the case of the normalising furnace.

Two electrically-driven rocker-arm pushers are provided at the charging end, one for each row of boxes, and these pushers are synchronised with the doors, of which there are four. These doors, together with the two pushers, are completely automatic, being operated electrically and controlled by a special time clock. The heating and soaking zones are under full automatic temperature control by means of Leeds and Northrup instruments.

The furnace is 5 ft. wide inside and 52 ft. 3 in. long between the doors, and is lined throughout with 9 in. of refractory backed up with 9 in. of highly efficient insulation. Similar burner equipment to that on the normalising furnace is also used on this furnace, and the working results show the furnace is highly efficient, in fact the output possible is considerably greater than that specified. When operating at a gross capacity of 1,200 lb. per hour with a heating cycle of approximately 18 hours, the gas consumption is 2,450 cub. ft. per hour.

Reheating Furnace

This furnace is of the continuous conveyer type, to deal with 500 lb. per hour of transmission gears and other components heated to 925° C., and the heating time is variable between 40 and 60 mins. The conveyer belt is totally enclosed within the furnace chamber, so that little heat is lost in its return passage to the charging end. This belt is built up of heat-resisting alloy, interlocking links fitted with rollers on the underside, a design which has been evolved after considerable practical experience in the construction of these conveyers. The rollers pass over skid rails, which are in turn supported by cross-members evenly spaced along the length of the furnace. The effectiveness of this design and construction is proved by the fact that a life of over three years has been obtained on one of these belts operating at 925° C.

Foot-operated doors provided with gas screens are arranged on each side of the furnace at the discharge end and through which the work is removed for quenching. Provision is also made to discharge to the atmosphere any work not removed from the conveyer by the operators. The furnace is efficiently insulated and fitted with automatic proportioning burner equipment, but in addition a metallic recuperator is provided to give still greater efficiency.

When dealing with 500 lb. of steel per hour heated to a temperature of 790° C. the gas consumption is 750 cub. ft. per hour.

This furnace is also under full automatic temperature control, using Leeds and Northrup instruments.

Drawing Furnace

In order to eliminate handling the material as much as possible, this furnace is actually built so that the mono-rail shop conveyer is utilised to carry the work through the furnace. The heating is by means of hot circulated air from an independently fired heater under full automatic control, and fitted with safety control devices.

Special provision is made at the charge and discharge ends to prevent loss of hot air through the open ends. Exhaustive tests show that these arrangements are very effective, and also that the temperature throughout the furnace is absolutely uniform. This latter is, of course, most essential in a draw furnace.

The whole installation was designed and constructed by British Furnaces, Ltd., of Chesterfield, in close co-operation with the metallurgical staff of Messrs. Vauxhall Motors, Ltd., to whom the author is indebted for permission to give these particulars.

Firms Holding Contracts with Government Departments : Notice

UNITED Kingdom firms under contract with Government departments for the supply of goods required for National Defence purposes are requested, if they should be experiencing difficulty in obtaining from abroad essential supplies ordered in connection with such Government contracts, to communicate immediately with the Department or Departments whose contracts are affected by these difficulties in order that such steps as may be possible may be taken to facilitate delivery of supplies.

The Departmental contract number should be quoted, and the commodity concerned should be indicated at the head of the communication. Full particulars should be then given of the nature of the difficulty which has arisen so far as oversea supplies are concerned, together with the name of the oversea firm and details of the order placed oversea.

Each communication should preferably be accompanied by two copies.

The Welding of Aluminium and its Alloys

The development of technique in the fabrication of metals is well indicated by progress in welding of aluminium and its alloys. At one time this operation was a very real problem; to-day, with modern technique and good quality materials, aluminium welding has been greatly simplified. Various types of welding are discussed, and brief reference made to the technique employed.

FAR-REACHING progress has been made in recent years in every branch of the aluminium industry, largely as a result of research which has facilitated the development of manufacturing technique in the many operations involved. Of the many operations in which progress is of an outstanding character that of welding is not the least important. In the early applications of aluminium satisfactory welding of parts was a very real problem in fabrication; at that time the difficulties were so great that it was regarded by many as an unsuitable metal for welding. Since that time, however, persistent research and experiment have greatly increased knowledge regarding suitable methods and revolutionary changes have taken place in the fabrication of aluminium structures by welding. To-day the welding of aluminium presents no difficulties providing the correct technique and good quality materials are employed.

There are three main processes by which aluminium and its alloys may be successfully welded: Fusion or autogeneous welding, using oxy-acetylene, oxy-hydrogen, or oxy-propane flames; electric arc fusion welding, including the metallic arc, carbon arc, and atomic hydrogen arc-welding processes; and electric resistance welding, including butt, spot and seam welding.

Fusion Welding

The oxy-acetylene or oxy-hydrogen blowpipe is the most widely used method, and is applicable to butt, lap, tee and fillet joints in the same manner as with any other metal. It is general practice to use the oxy-acetylene flame in preference to the oxy-hydrogen flame, since the former, as a rule, gives sounder and more ductile welds. Whatever gas is used the blowpipe should be kept scrupulously clean, and should be carefully adjusted to show its neutral flame, since this gives the best speed and economy, as well as a cleaner and sounder weld. A faulty or dirty tip will give indifferent results, and it should be cleaned frequently by blowing it out from the inside and not by pushing a needle through from the outside.

A wide variety of flame conditions is possible with acetylene by different adjustments of the blowpipe. A neutral flame is secured by reducing the amount of acetylene only until one white cone is visible. Outside of this cone is a nearly colourless flame of large volume. The neutral flame is not only the hottest, but it also prevents excessive oxidation of the molten metals by providing a reducing gas envelope. A slight excess of acetylene is satisfactory, but an excess of oxygen should be avoided. To adjust the welding flame under practical conditions, it is best to increase the stream of acetylene until two cones appear, and then to decrease it until only one cone is visible.

A highly refractory oxide film forms on aluminium immediately it is exposed to air, and the removal of this film is essential before a satisfactory weld can be made. In order to remove this oxide film a suitable flux is nearly always employed. Mechanical methods, such as the puddling method, are sometimes used, in which steel tools break up the film and allow the metal to freeze, but joints made in this way, without the use of flux, nearly always contain a certain amount of oxide, resulting in loss of strength, and it is advisable that fluxes be used.

From the book on "The Welding and Riveting of Aluminium," by Aluminium Union Ltd.

Butt Welding Aluminium.

The importance of using a good quality flux cannot be over-estimated. A satisfactory flux both dissolves the oxide on the surface of the metal and also prevents further oxidation taking place during the welding operation. Fluxes are most frequently mixtures of alkaline halides or sulphates of sodium, potassium and lithium, and often contain cryolite—a double fluoride of aluminium and sodium. Several proprietary fluxes are marketed which are reliable.

The flux can either be mixed with water to form a thin paste or used in its dry state; the welding rod, after being heated, is dipped into the dry flux, which adheres to it, and the flux is then melted up the rod to form a thin varnish. The gradual melting of the rod as the welding proceeds automatically feeds flux on to the weld at the position where it is required. In cases where no welding rod is used, as with certain flanged joints, the flux in paste form may be applied to the seam to be welded by means of a brush. Flux used in paste form should not be used again after standing overnight, as its composition is thereby modified and its fluidity and consistency impaired. All traces of flux should be removed after the weld is complete.

The choice of the correct welding rod or wire is of great importance. If welding pure aluminium sheet or plate the welding rod or wire should preferably consist of the same material. For the aluminium-manganese alloy either pure aluminium or a rod composed of the same alloy should be used. The heat-treated aluminium alloys are more easily welded by using a 5% silicon welding rod, though, where no stresses are placed on the metal while cooling, and where the parts are free to adjust themselves to expansion and contraction, a sounder weld can be made if a welding rod of the same composition as the parent metal is used. The latter method assists in preventing discolouration at the weld if the component is subsequently anodised. For certain difficult jobs a 10% silicon welding rod is used on account of the high fluidity of this alloy, but owing to its short solidification range particular care is necessary.

One caution should be remembered in the use of aluminium-silicon welding rods, when the components are to be subjected to solution heat-treatment after welding. The introduction of an appreciable amount of silicon into the weld lowers the safe temperature to which some of the strong alloys may be heated, so that none of these alloys should be heated above 500° C.

The preparation of the metal for welding affects very considerably both the quality of the weld and the cost. Cleanliness of the edges to be welded is of extreme importance; any trace of lubricant or grease must be removed before welding commences. For light-gauge sheet, up to 0·048 in. thick, the edges may be flanged to an angle of 90°, the height of the flange being about one and a half times the thickness of the metal. Welding wire or rod is then unnecessary, since the melting of the flanges when butting together provides the necessary material for the weld. Butt welds in sheet up to 0·0625 in. thick can best be made by butting the edges together after they have been notched. For heavy material, the edges should be bevelled to form a 90° vee, which should not extend through the entire thickness of the material, as a lip of between $\frac{1}{16}$ in. and $\frac{1}{8}$ in. should be left to define the edge. This lip should preferably be notched before welding. Material above $\frac{1}{2}$ in. thick can best be welded by bevelling both sides. The parts to be welded should be supported, so that the underside of the weld is free, in order that the added thickness of metal in the weld may form a slight bulge on the under surface, which can afterwards be dressed down if desired.

Owing to the relatively high coefficient of expansion of aluminium, precautions are necessary to avoid distortion in the finished sheet. The metal will expand on being heated and will contract again on cooling after the weld is complete, and the work should be arranged to enable this movement to take place freely. In some cases buckling cannot be avoided in welding plate and sheet, and although these buckles can generally be straightened out by hammering, care should be exercised in the welding operation to limit buckling as much as possible. The risk of distortion is reduced by preheating, and when sheet exceeding $\frac{3}{8}$ in. thick and the larger aluminium castings are to be welded it is advisable to preheat them to 370°–430° C. in order to avoid heat strains.

Electric Arc Welding

The electric arc welding process is divided into three classes—metallic arc, carbon arc, and atomic hydrogen arc welding. The metallic arc process is particularly applicable to certain classes of work such as attaching stiffeners to large flat surfaces. There is less buckling and warping of the work with arc welding than with torch welding, and preheating before welding can be largely eliminated. The temper of the sheet is less effected since the heat is much more concentrated and the weld made more quickly. Butt welds can easily be made by this process in material 0·08 in. and thicker, but lighter material is difficult to weld commercially. The welding rod used is generally 5% silicon alloy heavily coated with a special flux.

The electric generator required for arc welding aluminium is practically the same as that used for similar work in other metals. It should be a variable voltage machine, rated at 50 amperes or more on an open circuit voltage of about 60. For material up to $\frac{1}{2}$ in. thick a machine with a maximum capacity of 400 amperes is necessary. When connecting up the work and electrode holder, regardless of the alloy being welded or the thickness of the work, the polarity is with the electrode and the work negative, or what is usually called "reversed polarity." This is primarily done to improve the arc stability.

Owing to the complete penetration produced by the metallic arc, it is not necessary to prepare the edges of sheets up to about $\frac{1}{4}$ in. thick. For greater thickness the edges should be bevelled, leaving a lip on each edge. To strike the arc, the electrode should be brushed across the work, and a short arc is preferable. The electrode should be held vertically and worked backward and forward until a bead of the required height is built up.

The carbon arc can also be successfully adapted to welding certain joints in aluminium parts, but this method is not so flexible in application as metallic arc welding. The use of the carbon arc for welding aluminium is confined at present to butt joints, either straight or corner, and to simpler types of lap joints.

Atomic hydrogen arc welding can be used to advantage in many cases for repetition work, where a good "set up" is available and where no awkward shapes or corners interfere with the free movement of the torch and filler rod. To weld by this method a single-phase alternating current arc is struck between two tungsten electrodes, and hydrogen or cracked ammonia gas is blown through the arc. Atomic hydrogen is formed by the dissociation of the molecular hydrogen, which recombines at the surface of the metal being welded, giving a very hot concentrated flame. The hydrogen completely envelopes the weld, thus eliminating all possibility of the oxygen from the air combining with the molten metal. A filler rod is used as with autogeneous welding.

Resistance Welding

In resistance welding the welding heat is obtained by passing a heavy electric current through the pieces to be welded in such a manner that it flows from one piece to the other at the place where the weld is required. The heat is developed, due to the current flow through the resistance of the material, as well as through the contact resistance of the surfaces to be welded.

The types of resistance welding applicable to aluminium and its alloys are: Individual spot welding, continuous spot—or stitch—welding, roller seam welding, and butt welding. The equipment required is generally similar to that used for welding steel by this method, but a very much heavier welding current is necessary, while the duration of current flow is greatly reduced. An extremely accurate control of welding time and current, and of electrode pressure, is essential.

Aluminium and its alloys have a very high thermal and electrical conductivity, consequently in spot-welding maximum use must be made of the contact resistance between the metal sheets being welded. A very high current is required to obtain sufficient heat from this resistance before it disappears, and the current flow has to be very brief in order to avoid undue heating of the surrounding metal. The recent development of methods for the accurate control of welding current have made spot-welding a reliable and consistent method of assembling sheets of aluminium and its alloys particularly those which derive their strength from special heat-treatment.

The information given above has been abstracted from an excellent book entitled "The Welding and Riveting of Aluminium," recently published by Aluminium Union, Ltd., the Adelphi, Strand, London, W.C. 2, which presents practical information on welding and riveting processes, and directs attention to recent advances made in these processes.

Electrical Welding as an Integral Part of Structural Design

In his Andrew Laing Lecture to the North-East Coast Institution of Engineers and Shipbuilders, on November 10, 1939, Professor B. P. Haigh, M.B.E., D.Sc., dealing with the above subject, discussed thermal actions in arc-welding in relation to the security of the weld. The dangers of brittleness were emphasised, and considerable attention given to tests on structural details to illustrate the application of principles of design. It is only possible to deal briefly with the lecture in the following notes.

THE formation of a reliable weld demands fundamentally, alike in theory and in practice, that metal shall be deposited only on surfaces that are already molten. Practical men in future, even more than in the past, should aim to secure " penetration "—avoiding " lack of fusion " in joints required to stand the severe stresses that can be used with confidence in reasonably good work.

The thermal processes that occur in a welding arc are of considerable interest, and may be compared with those in an evaporator and condenser—or even in a complete turbine plant, for the discharge of moist vapour from the electrode is so rapid that the force of reaction is appreciable, setting an upper limit to the size that can be operated by hand: larger sizes can be controlled only by machines provided with automatic feed mechanisms. Although the rate at which the vapour is boiled off the electrode depends on the current used, the more important rate at which it condenses and crystallises upon the work depends more directly on the rate at which heat is conducted away from the molten puddle. In the open arcs that are generally used in welding, the two rates are not necessarily the same. It is wasteful to evaporate metal faster than it can condense upon the molten puddle, and dangerous to allow it to condense elsewhere, as lack of fusion may then remain in the finished weld.

After freezing, the deposit contracts in volume continuously with fall of temperature, and may expand or contract in different cases when changes of physical state occur at particular temperatures. In structural practice, these contractions result in warping and are commonly a cause of serious difficulty. Warping is often minimised by arranging that the warps due to successive runs occur in opposite directions.

The stresses induced in the deposit and adjacent metal by contraction during cooling are of different kinds, and commonly dangerous in different degrees, tending to cause cracking during cooling. When the layer of cooling metal is relatively thin, so that the stress acts only in two directions near the surface, the tension is commonly relieved by plastic strain in the metal before it can reach values high enough to cause cracking: thus, plastic strain serves as a " safety valve " in the metal. The conditions are often more dangerous in thicker welds when the different parts cool at different rates, particularly in the later stages of cooling when the outside is already cool and rigid while the inner part remains hotter and relatively liable to crack under the action of " triple " tensile stress. Two types of cracking can be distinguished in such cases: (1) the outside may crack in an earlier stage of cooling if or when it contracts too rapidly; and (2) the inside may crack at a later stage if or when it continues to contract after the outside has hardened. Cracking in high-tensile steels is often attributed to the presence of Martensite, but in this connection it should be borne in mind that the reduction of Martensite involves further contraction at low temperature, and is, therefore, liable to cause cracking of the second type mentioned. It is, of course, desirable that weld deposits should be endowed with ductility in sufficient degree to act as a safeguard against the simpler types of stress; but even ductile deposits are liable to crack under the action of " triple " tensile stress, and it is, therefore, desirable also to avoid differential cooling. Slow rates of cooling are beneficial in this respect, giving more time for equalisation of temperature and for the development of plastic strains tending to limit the stresses reached in the interior of the deposit.

The use of covered electrodes originated in Sweden, but developed more rapidly in England than abroad as the demand for tough reliability was more insistent, and the advantages of slag coverings on the deposit were appreciated more clearly. It may be feared that much of the anxiety that still besets the use of arc-welding survives from the unfortunate experiences of Continental users of bare-wire electrodes. Coverings operate beneficially in a number of ways: by keeping the electrode in shape to form a suitably short arc; by surrounding the stream of vapour by a gaseous tube that restricts the ingress of oxygen and nitrogen; by affecting the metallurgical analysis of the deposit; and—perhaps most important of all—by condensing to form a jacket of slag that prevents unduly rapid cooling and consequent cracking.

As the stream of metallic vapour in the arc is derived from the covering as well as from the wire, the metallurgical analysis of the deposit is controlled by both sources. In structural welds, the deposit usually contains only 0·08 to 0·10% of carbon—values that are low but sufficient, on account of the rapid rate of cooling, to give tough deposits with ample tensile strength to suit the requirements of structural steels. It is a fallacy to assume that higher carbon, giving greater tensile strength in samples cut wholly from deposited metal, is desirable for structural steels of higher tensile strengths: the ultimate and plastic strengths available with moderate or low carbon deposits are generally so high that tensile test-pieces cut from welded joints have to be notched in the deposit to force the fracture to occur there, rather than in a remote section through the plates. The fundamental requirement for obtaining high tensile test figures in welded joints is not generally a deposit of greater strength, but rather greater ductility, to ensure that the stress is distributed more uniformly across the section provided to carry the load.

Notched-bar Tests

Notched-bar bending tests have been widely used, and have proved valuable in three distinct directions: (1) In revealing brittleness from whatever the cause. In notched-bar tests, welded and unwelded samples alike are sensitive to temperature; and all mild steels in different degrees tend to become brittle when the temperature falls below limits that are generally only slightly below, and may be occasionally above, zero Centigrade. It appears that notched-bar tests, if they are to be carried out at all, should be directed to ascertain the limiting temperatures and other conditions under which steels become brittle, rather than simply to record the Izod value at any chance temperature. (2) Notched-bar tests are of special value for comparing different steels as regards suitability for welding, because the character of the stresses produced during the

test has much in common with those produced by internal contraction. (3) In a third direction also, notched-bar testing has contributed to the development of structural welding practice, and in a curious and almost unexpected manner; it has revealed with scientific precision sources of danger which, although recognised in practical experience, were not clearly, if at all, indicated in other mechanical tests, and were consequently liable to be regarded as heresies. Partly on account of this, the notched-bar test has become not only a serviceable auxiliary means of investigation, but also itself an object of scientific investigation.

Influence of Size on Brittleness

The influence of size in relation to the incidence of brittle fracture is perhaps the most curious of such actions, and certainly the most important in relation to structural practice. Practical observations, investigations and tests on samples show that large notched bars are necessarily brittle, even at ordinary temperatures, no matter how toughly ductile the metal may appear when tested in small-sized pieces. The danger of cracking arises even in the toughest of steels when the size exceeds certain limiting dimensions, and the determination of these safe limits for different steels appears to be a matter of considerable practical importance. Investigations, and experiences that prompted them show that, in structures liable to be even slightly deformed by collision or excessive static loads it is desirable to avoid the use of heavy forgings or castings, or even heavy plates, exceeding the limiting thickness of ductile bending. The remedy for brittle fracture in such parts is not the use of still heavier sections, which would prove only more brittle, but the use of lighter plates and rolled sections in a composite structure—such as can be arranged effectively and economically by the use of arc welding. This lesson has been applied with success in naval architecture, and in general structural practice.

Fatigue, Vibration and Corrosion-Fatigue

Fatigue cracking, and corrosion-fatigue in particular, differ in many respects from other forms of brittle fracture, and are of special interest in relation to the use of welded joints in lieu of riveted. It may be that many practical men, not lacking in experience of major disaster at sea or of the minor failures that fill the scrap-heaps of repairing yards, still hesitate to use the terms "fatigue" and "corrosion-fatigue," although they correctly ascribe many examples of cracking to the "working" of the ship at sea, or to vibration caused by the engines or propellers. The scientific term "fatigue" may be ill-chosen on account of its implications; but it signifies no more—and no less—than the effects of "working" or vibration.

It may be that scientists have created two false impressions, that very great numbers of repetitions of identical cycles of stress are necessary to cause fatigue cracking, and that the ranges of stress required are relatively high and unlikely to be reached in practice, unless the vibration of the engine or vessel is grossly evident and almost unbearable to all present in the vessel. In seeking to establish with extreme precision the limiting safe ranges under ideal conditions, they have extended their tests to many millions, and have used test-pieces with ideally finished surfaces giving unduly high optimum values that are often quite misleading when applied in practice. Much lower nominal ranges of stress suffice to cause cracking when concentrations occur locally, or even when the plates have ordinary black or pitted surfaces; and cracking occurs after relatively small numbers of cycles, when the ranges of stress exceed the reduced safe limits by even, say, 10 or 15%. The action of fatigue is cumulative—except when it is annealed before a crack has even started, metal never forgets what has happened in its past: a few cycles of unduly severe stress on one voyage, followed by a few more on another, gradually mount up to cause fracture after a relatively small total number of such cycles. On the other hand, a number of cycles of stresses approaching, but not exceeding, the limiting safe value, tend apparently to raise the value of the safe limit for subsequent loadings, and it is probable that this effect—known as "understressing"—is distinctly beneficial in ordinary practice.

When fatigue-cracking occurs in the hull of a vessel subject to engine or propeller vibration, it is commonly attributable to "corrosion-fatigue"—that strange conjoint chemical and mechanical action that leads to cracking after great number of cycles of even small stresses. It may be of interest to remember that corrosion-fatigue was first discovered at Greenwich nearly 25 years ago in the course of investigations carried out in connection with the development of weapons that have lost, unfortunately, little of their value during the interval. The discovery remained, however, almost unknown outside Admiralty circles until, in 1926, it was independently re-discovered by Dr. D. J. MacAdam, of the United States Naval Experimental Station at Annapolis, Maryland. Whereas the effect of corrosion prior to a fatigue test is generally only slight, the simultaneous action of corrosion and fatigue is dangerous in the extreme when prolonged: fracture occurs under small ranges of stress that would be amply safe if the metal were kept dry. The practical significance of the word "prolonged" differs in different cases, for the accumulation of, say, 100 million cycles is rapid when the frequency of vibration is fast. It may be largely due to this cause that high-frequency vibrations were formerly believed to be more dangerous than slower; and more dangerous they are indeed when endurance is judged by time rather than by number of cycles. Twenty-five years ago, it was discovered at Greenwich that the danger of corrosion-fatigue may be mitigated, in steel, by coating the steel with a layer of zinc applied by the familiar process of "hot-galvanising"—which checks the electrolytic action on which the action appears to depend; and subsequent investigations carried out in America by Speller and Munn showed that the action could be inhibited by using bichromate of potash or other substances in solution in the water.

Changes in Design due to Welding

Two elementary principles, the practical importance of the straight pull and of the triangle of forces as a basis of detail design, should ever be kept in mind in structural design. Respect for these principles will commonly double the strength of welded connections between rolled sections, and thereby justify the use of scantlings lighter than are now prescribed for general use. Lapped joints, whether riveted or welded, are much weaker than butt-welds. Channels and other unsymmetrical sections, when subject to shear, are commonly subjected to "secondary" stresses greater than the "primary" stresses calculated by $f/y = M/I$; such sections tend to warp and "trip" under the action of the secondary stresses, giving grounds for the erroneous impressions that high factors of safety are desirable and that theory, after all, may be of little service in design. Symmetrical sections that can be welded although they cannot readily be riveted, require only much lower factors of safety, provided that suitable precautions are taken to ensure that the lighter structures are immune against vibration and its consequences.

It should not be assumed that the full advantages to be gained by the use of welding in structural practice are immediately available when welded joints are substituted in lieu of riveted, although an important increase of strength does indeed follow at once. Results of more far-reaching consequence are attained when the plates and rolled sections are rearranged according to the elementary common-sense laws of mechanics, that are so hard to apply initially but so obvious when their applications have been found.

Tests have been carried out on structural details, to illustrate the application of these and other principles of design, and comparisons are drawn between riveted and welded examples. Welding provides the means of using a little sound metal in the right place instead of more elsewhere; and theory can assist common-sense in the search for the right place.

Business Notes and News

Ministry of Shipping Appoints Shipping Men

The Minister of Shipping, Sir John Gilmour, whose appointment we referred to in our last issue, announces that it is his intention to make the fullest use in his organisation of the services of shipping men, of whom some are already at work in the department.

With the approval of the Prime Minister, Sir John Gilmour has made the following appointments:—Sir F. Vernon Thomson, who was associated with the former Ministry of Shipping, has agreed to act as Principal Shipping Adviser and Controller of Commercial Shipping. Sir Cyril Hurcombe, who was Deputy Director and later Director of Commercial Services in the former Ministry of Shipping, will act as Director-General. The Secretary to the Ministry will be Sir E. Julian Foley, who has been since 1929 Under-Secretary in charge of the Mercantile Marine Department of the Board of Trade. That department will be merged in the new Ministry.

These appointments bring to the assistance of Sir John Gilmour a wide technical experience ofthe shipping industry.

Barrow Hæmatite Steel Co.

It is officially stated that the Barrow Hematite Steel Co. will continue to produce from their heavy steel department for the duration of the war. The agreement which had been made between the Barrow company and Colville's, Ltd., of Glasgow, that Colville's should take over the heavy steel contracts in January next year and the Barrow supply, has been cancelled. The Barrow company is exceedingly busy, and working near to capacity.

Manufacture of Explosives

The difficulties which were overcome in the problem of manufacturing the high explosive components, ammonium and nitrate, in sufficient quantities to meet the enormous demands of the last war were described by Mr. H. A. Humphrey when delivering the Melchett Lecture for 1939, at the Institute of Fuel recently. He told how, through the agency of Messrs. Brunner Mond and Co. and a band of dauntless scientists the whole system of manufacture was reorganised and, in fact, restarted. Previous to the war ammonium nitrate had only been manufactured in this country in small quantities, a scale totally inadequate to the war-time demands. The methods of production, too, were inapplicable to wholesale production.

By an intensive process of research and experiment, including the introduction of several novel methods of manufacture, and the expenditure of £6,000,000 in the establishment of new factories and the adaptation of others, the programme of requirements was fulfilled. Production went up by leaps and bounds, and, to mention only one factory, rose from 70 tons per week to 7,000 tons per week.

The Ural Aluminium Works

The first electrolytic plant of the Ural Aluminium Works was put into operation recently. With the starting of this plant the entire first section of the works is now in operation. These works, which are situated five miles from the town of Kamensk, was commenced in 1934. In respect of output capacity and technical equipment, they are claimed to have no equal in Europe. Its main shops and auxiliary enterprises occupy an area of more than 850 acres. The whole of the equipment and mechanism for the plant were manufactured in the U.S.S.R. At present work is proceeding on the building of the second section of the plant, the whole of which is expected to be in operation in 1940.

WANTED—Foundry Premises (or part) required for installing small 1-ton steel plant for munitions production or alloy steels. Iron Foundry, with available unused space, with Overhead Crane, etc., may suit. Plant and personnel available. Write in first instance to Box No. 104.

Films on Welding Subjects

A series of slide films on many aspects of arc welding have been prepared by the Lincoln Electric Co., Ltd., Welwyn Garden City, Herts. These films will be loaned free of charge to technical schools, technical societies, or engineering firms who wish to arrange lectures on electric welding.

The subjects included in the series are very comprehensive, and embrace: (*a*) "Arc Welded Construction of a Revolutionary Type of Industrial Building which entirely ignores Roof Trusses"; (*b*) "Brief Discussion of the Shielded Arc, Cost and Weight Comparisons of Welded Steel and Castings"; (*c*) "The Shielded Arc Process of Electric Welding"; (*d*) "Greater Profits in Manufacturing by Re-design"; (*e*) "Better Buildings and Structures at Lower Cost by Electric Welding"; (*f*) "Building Better Pipe Lines Faster and at Less Cost"; (*g*) "Surfacing by Electric Welding, an Opportunity for Big Savings"; (*h*) "Automatic Arc Welding by the Electronic Tornado"; (*i*) "Safety and Health in Arc Welding."

Each of the sets of slide films comprise some 30 to 40 pictures, diagrams, etc., and with each is distributed the text of the accompanying lecture to be given with the film. The Lincoln Co. are also supplying a projector, by means of which these slide films can be shown on any screen or white wall. This service by the company was introduced experimentally last year and proved very popular, and the service has now been considerably extended for the coming winter months.

Sub-Contractors' List for Work of National Importance

The Association of British Chambers of Commerce have received a suggestion that many large contracting firms engaged on contract work of national importance would be glad to have the names of sub-contractors who are ready and in a position to assist the large firms in carrying out their work.

In order that the names of these sub-contractors may be available, it is suggested that a register should be compiled of (*a*) firms who are in a position to accept sub-contracts; and (*b*) firms desiring assistance of sub-contractors.

It is the intention of the Association of British Chambers of Commerce, therefore, to compile a list of the names and addresses of such firms under the two categories (*a*) and (*b*) above, and in due course to circulate lists to chambers for the information of their members.

Chambers of Commerce throughout the country are therefore compiling lists of those members who are desirous of having their names included in the register, giving the following information:—(*a*) Description of sub-contract or assistance which can be given; (*b*) description of assistance required.

A.R.P. Basement Protection

Designs and materials for reinforcement of basements have been produced by the Exors. of James Mills Ltd., Stockport. There are two plans—one for the basements of larger warehouses, stores and large residences, and the other for smaller warehouses and offices, private houses, shops, and similar property.

For the larger buildings the vertical pillars supporting the ceiling reinforcement are of 3-in. O.D. tube (six-gauge), with their lower ends threaded for adjustment to their base-plates, and erected with cross lacing to prevent side slip and to add to resistance against deflection. Above the 6 in. × 3 in. steel girders are specially-rolled splinter-proof steel sheets of "W" section. With adequate spacing of the shores, this larger type will carry an ultimate load of one ton per square foot of ceiling space. The smaller, lighter design employs 14-gauge corrugated sheets, 4 in. × 3 in. girders, and 3-in. tube shores; and this type with correct spacing will carry a debris load of 400 lb. per square foot.

W. H. A. Robertson and Co., Ltd., Lynton Works, Bedford, have issued a brochure which illustrates typical examples of the many machines this Company has supplied to leading aircraft manufacturers in the United Kingdom and abroad. Information is given of forming mills, slitters, drawbenches, strip and sheet flattening machines, rod wire mills, etc., and although, in nearly all cases, it is necessary to modify designs to suit particular requirements, this Company specialises in such types of work, but this brochure gives a general idea of the types of machines which are available. Copies can be obtained on application to the above address.

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